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THESIS

APPLYING RISK MANAGEMENT TO REDUCE THE TIME IN LAY-UP WHILE INCREASING THE COST EFFECTIVENESS OF A NIMITZ (CVN 68) CLASS AIRCRAFT CARRIER IN DRY DOCK DURING THE EXECUTION PHASE OF A REFUELING AND COMPLEX OVERHAUL

by

Kiah Bernard Rahming

March 2009

Thesis Advisor:	Gary O. Langford
Second Reader:	Paul V. Shebalin

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13. ABSTRACT (maximum 200 words)

The Refueling and Complex Overhaul (RCOH) of an aircraft carrier is one of the most important milestones in a carrier's lifecycle. An RCOH supports the future modernization efforts that will sustain the carrier and extend its nuclear fuel lifetime an additional twenty-five years. To date only two Nimitz class carrier overhauls have been completed, with a third in progress. Although these RCOHs were viewed as overall successes, they were unsuccessful from a risk management perspective because ultimately resulted in consecutive delivery delay and increased cost. This research assessed three (3) possible risk mitigation strategies for achieving cost and time effectiveness of a Nimitz class nuclear powered aircraft carrier (CVN) in dry-dock during the execution phase of an RCOH. The strategies evaluated were (1) to maintain the current RCOH process, (2) reduce and defer non-nuclear maintenance coupled with schedule compression, and (3) increase the efficiency of power usage of carriers with the intent of eliminating the need for refuelings. The results of this research indicate that eliminating a carrier's RCOH increases its overall cost and time effectiveness. It also reveals that a 33-year carrier lifecycle, as opposed to a 50-year lifecycle, increases the ship's operational availability and modernization capability.

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Kiah Bernard Rahming
Lieutenant, United States Navy
B.S., Oakwood University, 1998

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Author: Kiah Bernard Rahming

Approved by: Professor Gary O. Langford
Thesis Advisor

Dr. Paul V. Shebalin
Second Reader

Dr. David H. Olwell
Chairman, Department of Systems Engineering

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ABSTRACT

The Refueling and Complex Overhaul (RCOH) of an aircraft carrier is one of the most important milestones in a carrier's lifecycle. An RCOH supports the future modernization efforts that will sustain the carrier and extend its nuclear fuel lifetime an additional twenty-five years. To date, only two Nimitz class carrier overhauls have been completed, with a third in progress. Although these RCOHs were viewed as overall successes, they were unsuccessful from a risk management perspective because ultimately resulted in consecutive delivery delay and increased cost. This research assessed three (3) possible risk mitigation strategies for achieving cost and time effectiveness of a Nimitz class nuclear powered aircraft carrier (CVN) in dry-dock during the execution phase of an RCOH. The strategies evaluated were (1) to maintain the current RCOH process, (2) reduce and defer non-nuclear maintenance coupled with schedule compression, and (3) increase the efficiency of power usage of carriers with the intent of eliminating the need for refuelings. The results of this research indicate that eliminating a carrier's RCOH increases its overall cost and time effectiveness. It also reveals that a 33-year carrier lifecycle, as opposed to a 50-year lifecycle, increases the ship's operational availability and modernization capability.

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EXECUTIVE SUMMARY

This research addressed the complexity associated with refueling and complex overhauls (RCOH)s. An RCOH is comprised of three contractual phases that include planning, execution, and a post selective availability. This thesis specifically examines the Navy's ongoing challenge of increasing the cost and time effectiveness of Nimitz-class aircraft carriers in dry-dock during the execution phase of an RCOH. Cost effectiveness was defined by this research as the best tangible outcome compared to the total cost expended. It was also broadly defined as the following.

- less cost for the more performance (work accomplished)
- less cost for the same performance
- less cost for less performance
- same cost for more performance

Time effectiveness (TE) was defined as any modification(s) in planning scheduling and/or conducting an overhaul that resulted in an RCOH schedule duration of less than or equal to 33 months. It was also broadly defined as the following.

- less time for the more performance (work accomplished)
- less time for the same performance
- less time for less performance
- same time for more performance

The research methodology used was basic risk management within the structure of the systems engineering process. Risk management is an iterative process of identifying and measuring unknowns, developing mitigation strategies, selecting, planning and implementing appropriate risk mitigations, and tracking the implementation to ensure successful risk reduction.

This research showed the importance of assessing the current process of planning and executing RCOHs to provide insights that addressed the notion of increasing cost and time effectiveness.

Chapter I described the origin and importance of a carrier RCOH. Chapter II defined risk, its key terms, descriptions, and principles. Chapter III utilized a stakeholder

analysis and a high-level functional (physical) decomposition of "Conduct RCOH" to discover the two main objectives of (1) reducing the time in lay-up and (2) increasing cost effectiveness. Chapter IV described the processes of an RCOH within the context of these two main objectives. Potential risks were evaluated through the standard assessment of likelihood, consequences, and impact on cost, schedule, and performance. Chapter IV concluded with a risk matrix and three mitigation strategies that evaluated cost and time effectiveness. The first strategy was to assume the current process of planning and conducting RCOHs was the most efficient method because it leveraged the lessons learned from each previous overhaul. The second strategy was to control and transfer the consequence of excessive cost growth and schedule delay by reducing and deferring certain types of work typically performed during an RCOH while concurrently applying schedule compression techniques. In this option, mainly critical path (nuclear propulsion) maintenance would be performed during an overhaul. The third strategy was to avoid the consequence of excessive cost growth and schedule delay by increasing the power efficiency of carrier's nuclear reactors with the goal of eliminating refuelings.

Chapter V discussed four primary types of maintenance performed during an RCOH and assessed the three mitigation strategies derived at the end of Chapter IV. The planning and execution of an RCOH was discussed in detail as well as the implications associated with maintaining the current process. Chapter V then discussed the impacts of reducing the scope of work in the availability work package (AWP) while compressing the overall schedule. Since work was not usually removed from the nuclear work package during previous RCOHs, the research suggested removing a reasonable amount of non-nuclear maintenance from the AWP. Also, the recent advancements in reactor technologies and the possibility for more power efficient carriers was discussed. An analysis of alternatives (AoA) was provided to illustrate graphically the differences in the strategies. Lastly, a solution was determined.

Chapter VI was a comparative analysis of the three mitigation strategies followed by the solutions suggested by the research. Trade-offs between the solutions were discussed and the author's findings, recommendations, conclusions, and questions for future work were presented.

Finally, through basic systems engineering and risk management techniques, multiple solutions for addressing the ongoing challenges associated carrier RCOHs were shown to be available. This research demonstrated that it was more effective in cost and time to discontinue performing RCOHs and to adapt a 33-year carrier lifecycle strategy that in 100 years would save the Navy approximately $53.32 billion.

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I. INTRODUCTION

A. PURPOSE

The purpose of this thesis was to provide alternate solutions for performing the execution phase of a refueling and complex overhaul (RCOH) that increase its cost and time effectiveness. The goal of this research is to assess the impacts to an RCOH by reducing the risk associated with its planning, scheduling, and execution.

The main thrust of this study was to evaluate the relationship between the two parameters of cost and time as they relate to an RCOH. This research then investigated three strategies for cost and time effectiveness as they pertained to the current challenge of aircraft carrier excessive cost growth and delivery delay during an RCOH.

B. BACKGROUND

The Norfolk Naval Shipyard is the oldest naval shipyard in America. Established in 1767, and initially known as the Gosport Navy Yard, it housed the first dry dock in the western hemisphere. A dry dock is a basin or vessel whose volume is slightly larger than the dimensions of an incoming ship, allowing water to be added and removed from around a ship so work crews can gain access to the hull for purposes of construction, maintenance, repair, and access to/from waterways. With Congress's requirements for a larger, faster, and more powerful Naval fleet during the War of 1812, the country's first graving dry dock was constructed at Gosport in 1833. Shown in Figure 1, a graving dry dock is a dry dock that is excavated into the ground. Its walls are lined with concrete and separated from a main body of water by a watertight gate called a caisson. Utilizing this dry dock and others like it, the Navy and industry created an experienced workforce and the technical expertise to construct and repair a variety of warships [1].

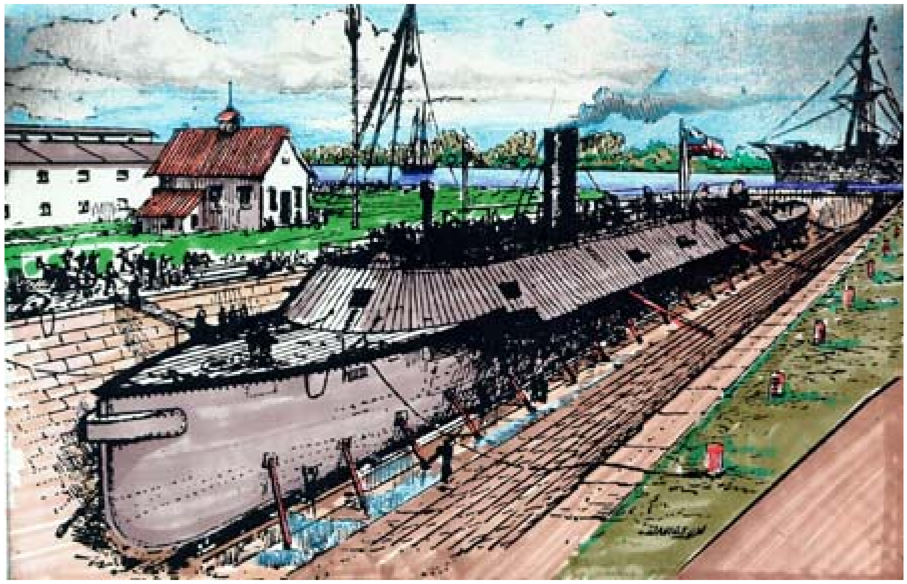

Figure 1. Graving Dry Dock (From: [2])

In 1920, using the ship construction technology of the previous era, the Navy conducted an experiment to convert the USS JUPITER (Collier 3) into a more versatile and technologically innovative war fighting vessel. The conversion was completed in 1922, and the USS LANGLEY (previously USS JUPITER) was commissioned as the Navy's first conventional aircraft carrier (CV-1) [3], [4] shown in Figure 2.

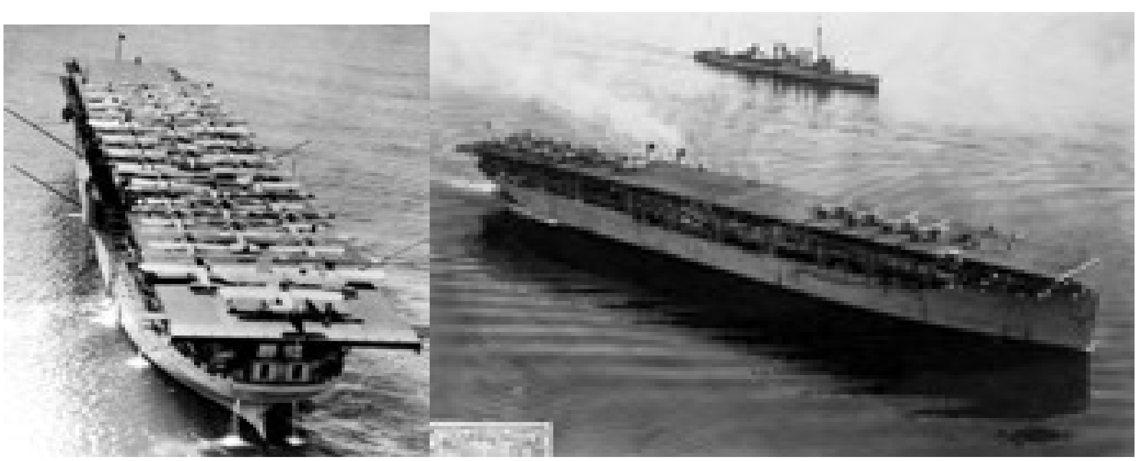

Figure 2. USS Langley (CV-1) (From: [5])

In an effort to create more powerful, faster, and self-sustaining aircraft carriers, the Navy began to incorporate nuclear propulsion into the carrier platform designs. The USS ENTERPRISE (CVN 65), shown in Figure 3, became the world's first nuclear-powered aircraft carrier in 1960 [6]. From this design, the USS NIMITZ (CVN 68), a supercarrier, was created and functioned as the template for all future nuclear powered carriers. Nimitz class carriers are designated as supercarriers due to their sheer size. They can characteristically displace up to 102,000 tons when fully loaded [7]. At the end of World War II, the United States Navy emerged as the premier naval fighting force in the world; however, the end of the Cold War resulted in a steady decline in naval fleet forces. Due to the reduced amount of carriers in service and their high operational tempo, carriers are required to refuel their nuclear reactors periodically in addition to accomplishing maintenance, repairs, and modernization alterations. These maintenance periods are called refueling and complex overhauls (RCOH).

Figure 3. USS Enterprise Underway (From: [7])

The RCOH of an aircraft carrier is one of the most important milestones in a carrier's lifecycle because it supports the future modernization efforts that will sustain the carrier until the end of its planned 50-year service life. An RCOH occurs approximately

around the midlife of the carrier. It is one of the most challenging industrial and engineering undertakings by the Navy due to the massive amount of planning, budgeting, and management that must occur. At its midlife, an aircraft carrier is scheduled to undergo a 33-month maintenance period to refuel its nuclear reactors, upgrade and modernize combat and communication systems, and overhaul the ship's hull, mechanical and electrical systems. Upon redelivery, the carrier is fueled for its remaining lifecycle service [8].

The ENTERPRISE was the first conventional aircraft carrier to conduct an RCOH in 1964. Although she completed four overhauls, the refueling of a nuclear powered supercarrier did not occur until 1998 with the USS NIMITZ (CVN 68) [9]. The second Nimitz-class carrier to conduct an RCOH was the USS DWIGHT D. EISENHOWER (CVN 69) which completed her overhaul in March 2005 [10], and lastly, the USS CARL VINSON (CVN 70) commenced her RCOH late in 2005 [11]. In total, two completed RCOHs serve as cost and schedule analysis blueprints.

Although these RCOHs were considered successes overall, via this research, the author believes the RCOH process should have been considered unsuccessful because it ultimately resulted in consecutive delivery delays and cost increases for the government.

For example, the scheduled completion of the RCOH for the USS NIMITZ (Figure 4) slipped by several months and resulted in significant cost growth. The primary causes were due to a fluctuating budget, changing work-requirements, and a four-month labor-union strike. The non-nuclear portion of the schedule slipped by several months and the contract increased 20% over the negotiated price (2.2 billion dollars). The initial awarded contract was for 33 months at 1.2 billion dollars [9, pp. 2, 34]. There should be a better way to manage risk for both the government and the contractors.

Figure 4. USS Nimitz in Drydock (From: [12])

The USS DWIGHT D. EISENHOWER (CVN 69) as shown in Figure 5 was redelivered after a four-year scheduled downtime, costing approximately $3.18 billion. The initial award contract was for 36 months at $1.36 billion [13], [10], [14].

Figure 5. USS Dwight D. Eisenhower in Drydock (From: [15])

Northrop Grumman was awarded a $1.94 billion cost-plus-incentive-fee contract for accomplishment of the fiscal year 2006 RCOH of the USS CARL VINSON (CVN 70) shown in Figure 6. The United States Department of Defense comptroller's “Program Acquisition Costs by Weapon System” document lists split-funding for the CVN 70 RCOH over FY2006-2007, with a total cost of $3.12 billion extended over 33 months of maintenance [11], [13].

Figure 6. USS Carl Vinson in Drydock (From: [16])

It is imperative for the Navy that carriers enter and exit dry dock in an expeditious manner to reduce the overall planning, management, and production costs associated with an RCOH.

C. RESEARCH QUESTION

The research question described in this section is developed to focus the thesis and to shape the research and subsequent analysis of data and information collected. It corresponds with the subjects of Chapters II, III, IV, V, and VI, respectively. The methodology presented in Section F was used to address the research question. The results and conclusions of the research question and of the thesis premise are summarized

in Chapter VI. By reducing risk, how can the Navy decrease the time in lay-up and increase the cost effectiveness of a Nimitz-class aircraft carrier in dry dock during the execution phase of an RCOH?

D. SCOPE

This research was scoped to include the direct risks associated with planning, scheduling, and executing an RCOH.

E. BENEFITS OF STUDY

The major benefit of this study is that it provided three strategies that assessed the notion of increasing cost and time effectiveness of a Nimitz-class aircraft carrier in dry dock during the execution phase of an RCOH.

F. METHODOLOGY

The methodology used to develop this thesis was to apply basic risk management within the structure of systems engineering analysis. Below is the general thesis methodology described in the context of this analysis process.

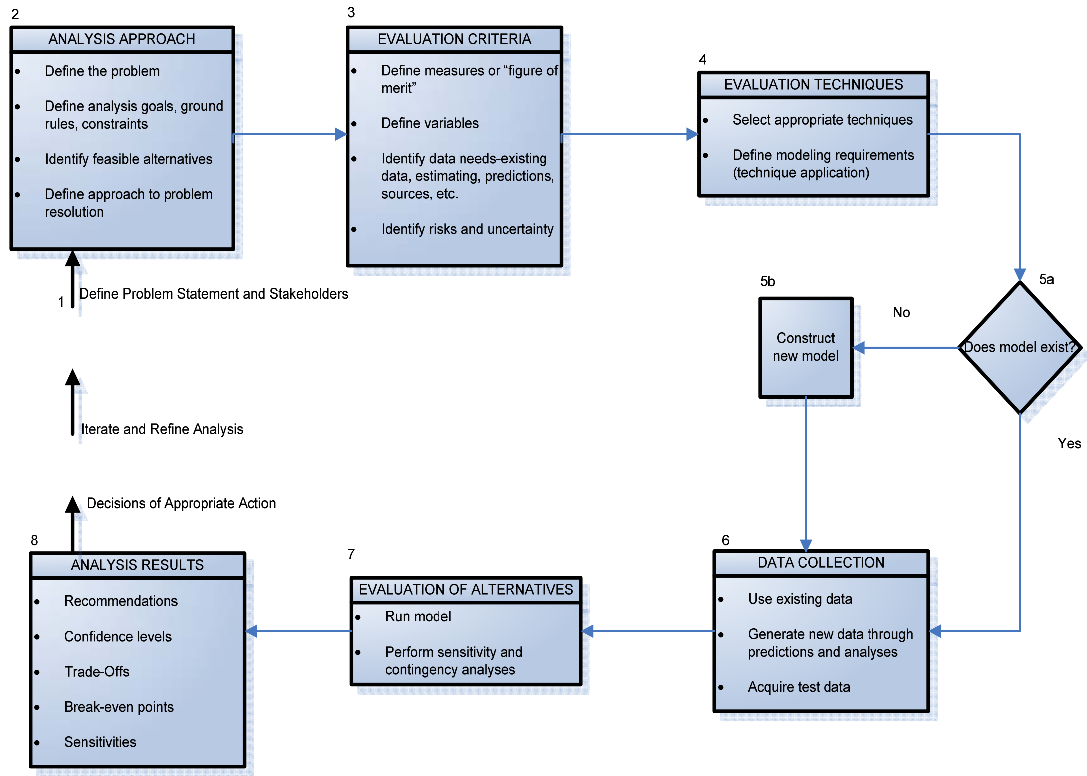

Figure 7. Generic Engineering Analysis Process (After: [17, p. 112])

1. Define Problem Statement and Stakeholders for Thesis Coordination

The problem statement addressed by this thesis is stated as: How can the Navy conduct RCOHs that are more cost and time effective? With an economy in recovery and the current administration's necessary scrutiny of military programs, it is imperative that the Navy determine a solution or solutions to stem the growing costs of overhauls by minimizing the impact on production cost, schedule, and performance. Organizations with which this thesis has been coordinated are as follows.

- Naval Postgraduate School (NPS)
- Supervisor of Shipbuilding Newport News Virginia (SUPSHIP NN)
- Northrop Grumman Corporation (NGC)

2. Analysis Approach

The approach used to analyze and evaluate this research was both quantitative and qualitative analysis within the structure of risk management. Risk management is an

iterative process of identifying and measuring unknowns, developing mitigation strategies, selecting, planning and implementing appropriate risk mitigations, and tracking the implementation to ensure successful risk reduction.

a. Develop Essential Element of Analysis (EEAs) and Constraints

The EEA of this thesis is the research question and the constraints are the time and information accessibility.

b. Measures of Effectiveness (MOE)

The MOE of this research are cost effectiveness and time effectiveness of an RCOH. Cost effectiveness (C_{eff}) relates to the measure of a system in terms of mission fulfillment and total lifecycle cost, and can be expressed in various ways, depending on the specific mission or system parameters evaluated [17, p. 437]. The equation below defines cost effectiveness or cost figure of merit (CFOM) as the availability of an aircraft carrier divided by its lifecycle cost.

$$Cost\ Figure-of-merit\ (CFOM) = \frac{availability}{lifecycle\ cost}$$ [17, p. 437]

Availability is presented as the figure-of-merit that assigns to each ship system the probability that the overall performance for the ship system will not be in failure mode when any user requires a demand to use the ship system in a manner typical of “normal” or “acceptable” operations. Availability is defined as the probability that the system will not be in a failed state or failing when service is required. Availability accounts for reliability and maintainability.

Lifecycle cost is presented as the figure-of-merit that assigns to each ship system the probability that the overall performance for the ship system will not be after its end-of-life. The lifecycle cost figure-of-merit includes acquisition, installation, design, development, operations, maintenance, support, and disposal. Lifecycle is defined as the probability that the system has not been disposed of.

Cost effectiveness is the ratio of the availability figure-of-merit divided by the lifecycle cost figure-of-merit. It is a number between 0 and 1 or 0% and 100%.

$$A_i = \frac{Uptime}{Uptime + Downtime} = \frac{Uptime}{Lifecycle\ time}$$

Analogously,

$$A_i = \frac{MTBF}{(MTBF + MTTR) + (Schedule\ Downtime)} \quad [17,\ pp.\ 435\text{-}436]$$

$MTBF = Meantime\ between\ failures$
$MTTR = Meantime\ to\ repair$
$A_i = Inherent\ availability\ (chosen\ because\ standby$
$and\ delay\ times\ associated\ with\ scheduled$
$downtimes\ are\ not\ included)$

If the scheduled downtime is both periodic and predictable, then after time, t, there is a scheduled downtime of αt. The percentage of time that the ship is not in maintenance is given by $\frac{t}{t+\alpha t}$ or $\frac{1}{(1+\alpha)}$ [18]. Therefore, the scheduled downtime increases the lifecycle time by (1+α), so that $A_i = \frac{MTBF}{(1+\alpha)(MTBF + MTTR)}$. This model of A_i assumes independence between failure rates, repair times, and time to repair. To improve the precision of the availability model, one must include operating time, standby time, schedule and unscheduled maintenance times, time to wait for supply parts, processing times and other delays [19]. Using the same form as used for A_i, these additional delays can be accounted for in the same manner by simply including them in the parameter α. Therefore,

$$A_o = \frac{MTBM}{(MTBM + MDT)(1+\alpha)}$$

. [17, p. 436]

$MTBM = Meantime\ between\ maintenance$
$MDT = Mean\ downtime$

Cost effectiveness of an RCOH (designated as C_{eff}) can be defined as the total cost of an RCOH divided by the lifecycle cost of a carrier or the total cost of an RCOH divided by the service life expectancy of an aircraft carrier [20].

$$C_{RCOH} = \frac{cost\ of\ RCOH}{lifecycle\ cost} = \frac{Planning_{cost} + Execution_{cost} + Post\ Selective\ Availabilty_{cost}}{lifecycle\ cost}$$

or

$$C_{RCOH} = \frac{cost\ of\ RCOH}{service\ life\ expectancy}$$

This research also defines C_{eff} as any change in planning scheduling and/or conducting an RCOH that result in the following (Figure 8).

- less cost for the more performance
- less cost for the same amount of performance
- less cost for less performance

same cost for more performance COST EFFECTIVENESS			
<	Cost	>	Performance
<	Cost	=	Performance
<	Cost	<	Performance
=	Cost	>	Performance
=	Cost	=	Performance
>	Cost	=	Performance
>	Cost	<	Performance
=	Cost	<	Performance

Figure 8. Cost Effectiveness

Highlighted in red in Figure 8 is cost ineffectiveness (C_{ineff}), which is defined as any change in planning, scheduling, and/or conducting an RCOH that results in the following.

- more cost for the same amount of performance
- more cost for the less performance
- same cost for less performance

The baseline for C_{eff} is the same cost for the same amount of performance as a previous RCOH (highlighted in sky blue in Figure 8). Performance is measured as the amount of work accomplished during an RCOH; however, it could be assessed as the accomplishment of a system's functions as specified by that system's requirements. In this case, deviations from performance requirements result in losses. This research assumed the baseline cost of the execution phase of an RCOH to be approximately $1.9 billion. This figure was based on the current (actual) cost of the CVN 70's overhaul and the assumption that the program office implemented the lessons learned, earned value management techniques, and cost savings strategies revealed at the CVN 68 and CVN 69 "hot-washes" (meeting that discusses a project's overall successes, failures, and lessons learned during an RCOH).

Time effectiveness (T_{eff}) is defined as any change in planning scheduling and/or conducting an overhaul that results in a scheduled duration of equal to or less than 33 months [21]. For example, the CVN 68 RCOH was completed after approximately 37 months while the CVN 69 RCOH was completed after 48 months [9, pp. 1, 2, 97], [10]. Therefore, both of these RCOHs are considered time ineffective because their ratios are greater than one.

$$\frac{\textit{actual RCOH duration}}{\textit{planned RCOH duration}} = \frac{\textit{actual CVN } 68_{RCOH}\textit{(Months)}}{\textit{planned CVN } 68_{RCOH}\textit{(Months)}} \approx \frac{37}{33} = 1.12$$

$$\frac{\textit{actual RCOH duration}}{\textit{planned RCOH duration}} = \frac{\textit{actual CVN } 69_{RCOH}\textit{(Months)}}{\textit{planned CVN } 69_{RCOH}\textit{(Months)}} \approx \frac{48}{33} = 1.45$$

Shown in Figure 9, T_{eff} is further defined and used by this research as any change in planning, scheduling and/or conducting an RCOH that result in the following.

- less time for the more performance
- less time for the same amount of performance
- less time for less performance
- same time for more performance

TIME EFFECTIVENESS			
<	Time	>	Performance
<	Time	=	Performance
<	Time	<	Performance
=	Time	>	Performance
=	Time	=	Performance
>	Time	=	Performance
>	Time	<	Performance
=	Time	<	Performance

Figure 9. Time Effectiveness

Highlighted in red in Figure 9 is time ineffectiveness (T_{ineff}), which is defined as any modifications in planning, scheduling, and/or conducting an RCOH that result in the following.

- more time for the same amount of performance
- more time for the less performance
- more time for less performance

The baseline for T_{eff} is highlighted in sky blue in Figure 9. As stated previously, performance is measured as the amount of work accomplished during an RCOH or as the accomplishment of a system's functions as specified by that system's requirements. This research assumed the baseline duration of an RCOH to be 33 months. The 33-month schedule duration is based on the Navy's desire to have a carrier asset operationally unavailable for the least amount of time possible, while supplying enough reasonable time to accomplish the necessary maintenance repairs, modifications and upgrades to sustain the ship throughout its remaining service life.

c. Identify Premise or Feasibility Alternatives

The analysis conducted in this thesis centered on identifying three feasible alternatives to the problem statement.

- The first strategy is to assume the risk of excessive cost growth and schedule delay by maintaining the current process.
- The second strategy is to control and transfer the risk of excessive cost growth and schedule delay through work redistribution, cancellation, and deferment.
- The third strategy is to avoid the risk of excessive cost growth and schedule delay by increasing the power efficiency of carriers with the goal of eliminating the need for refuelings.

d. Define Approach to Problem Resolution

The general approach for problem resolution of this thesis was risk management within the scope of the systems engineering process. The research question was addressed through a comprehensive literature review, qualitative analysis, quantitative analysis, expert interviews, and personal experience (For two years, the author served as an Assistant Project Officer (APO) at the Supervisor of Shipbuiliding in Newport News, VA during the USS CARL VINSON's RCOH. His primary responsibilities included Work Integration Leader, Customer Contracted Team Manager, and government oversight of the North Grumman Newport News Shipbuilding planning and execution contracts).

This study began by discussing the origin and importance of a carrier RCOH. Risk was defined as well as its key terms, descriptions, and principles. A stakeholder analysis and high-level functional decomposition of "Conduct RCOH" was performed to reveal the main objectives of (1) reducing the time in layup and (2) increasing cost effectiveness. A process flow diagram of an RCOH was illustrated within the context of the two main objectives and potential risks were evaluated through the standard assessment of likelihood, consequences, and impact on cost, schedule, and performance. Then, a risk matrix and three mitigation strategies for time and cost effectiveness were developed.

The three mitigation strategies were evaluated through a comparative analysis and by using the cost and time effectiveness criteria defined above in Section F.2.b (page 9). An analysis of alternatives (AoA) was conducted to evaluate the solutions from various stakeholder perspectives and the author presented findings, recommendations, and questions relevant to future research.

3. Evaluation Criteria

a. Identify Data Needs

This step determined the information and data needed to address the research questions. Publications discussed carrier overhauls, DoD policies and guidance, and reference models required for this thesis. Publications were read for existing research in the area of the EEAs, defined in this thesis to determine whether these questions had already been addressed.

b. Identify Risks and Uncertainty

There was no risk in completing this thesis due to cost issues, since funding was not required. There was minimal schedule risk since planning and preparation for completion began a year before the thesis was due. There was medium risk in the area of technical performance due to the uncertainty associated with attainting relevant desired data from subject matter experts within both government and industry.

4. Evaluation Techniques

The specific techniques used to address the thesis research question and to evaluate this premise were qualitative analysis, quantitative analysis, general probability and statistics, and the software application Probability/Consequences Screening, version 4.3.2, July 2006, developed by ASC/ENS, Wright-Patterson AFB Ohio. The overall techniques used included literature research and review, subject matter expert interviews and personal experience. No architecture products, mathematical models, or simulations were required to address the research questions.

5. Obtain, Construct and/or Verify and Validate Models

Formal models were not constructed as a product of this thesis.

6. Source Data Collection

Information was gathered through the coordination of government officials within the ship building industry. The NPS Library was used to query the EBSCOhost, BOSUN, DTIC, and IEEE Xplore databases for professional journal articles, conference proceedings and DoD policies, directives, instructions, manuals, and guides in search of information and data pertaining to the research questions.

The literature was initially scanned to determine whether the research questions had been previously addressed, or if the questions were otherwise easily answered by existing publications. This review revealed some relevant reference documents, but no comprehensive, consolidated documentation that addressed the research questions in the context of the thesis premise.

The initial scan was followed by an in-depth literature review for pertinent information required to support the research questions.

7. Evaluation of Alternatives

The results of the research were evaluated and a determination was made on the validity of the premise, referencing supporting information, and data.

8. Results and Recommendations

Findings associated with the research question were discussed in the appropriate chapters and conclusions were drawn based on interpretation of the results in the context of the research questions. Recommendations were made for improvement of RCOH planning methodology. Conclusions were drawn regarding the validity of the thesis premise.

After the results and recommendations were coordinated with NPS, SUPSHIP NN, and NGC, the final thesis was submitted to NPS for processing and public release.

9. Iterate and Refine the Analysis

Feedback on the published thesis may generate more or expanded research questions. This thesis may be revisited for expansion or refocusing of the scope, in which case, all or part of the methodology could be repeated, making the necessary modifications.

G. SUMMARY

This chapter provided an introduction and overview of this thesis, including the purpose, background, research question, scope, benefits, and methodology.

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II. RISK MANAGEMENT PROCESS

A. RISK

The methodology used to address the research question defined in Chapter I is risk management within the structure of the systems engineering process. Risk was defined as a measure of future uncertainties in achieving program performance goals and objectives within defined cost, schedule and performance constraints. It can be associated with all aspects of a program as they relate across the Work Breakdown Structure (WBS) and Integrated Master Schedule (IMS). It addresses the potential variation in the planned approach and its expected outcome [22, p. 1]. It is further described by equation [2-1] below as the product of the likelihood and impact of a given event over a time horizon.

$$RISK\left(\frac{consequence}{time}\right) = LIKELIHOOD\left(\frac{event}{time}\right) * IMPACT\left(\frac{consequence}{event}\right) \quad (2\text{-}1)$$

Risk is a qualitative measure determined through statistical analysis or subject matter expertise.

B. RISK MANAGEMENT

Risk management is an iterative process accomplished throughout the lifecycle of a system. It is an organized and systematic methodology for continuously doing the following.

- identifying and measuring unknowns
- developing mitigation strategies
- selecting, planning, and implementing appropriate risk mitigations
- tracking the implementation to ensure successful risk reduction

Effective risk management depends on risk management planning; early identification and analyses of unknowns; early implementation of corrective actions; continuous monitoring and reassessment; and communication, documentation, and coordination [22, p. 3].

C. RISK MANAGEMENT PROCESS MODEL

The risk management process model (Figure 10) includes the following key activities, performed on an iterative basis [22, p. 4].

- Risk Identification
- Risk Analysis
- Risk Mitigation Planning
- Risk Mitigation Plan Implementation
- Risk Tracking

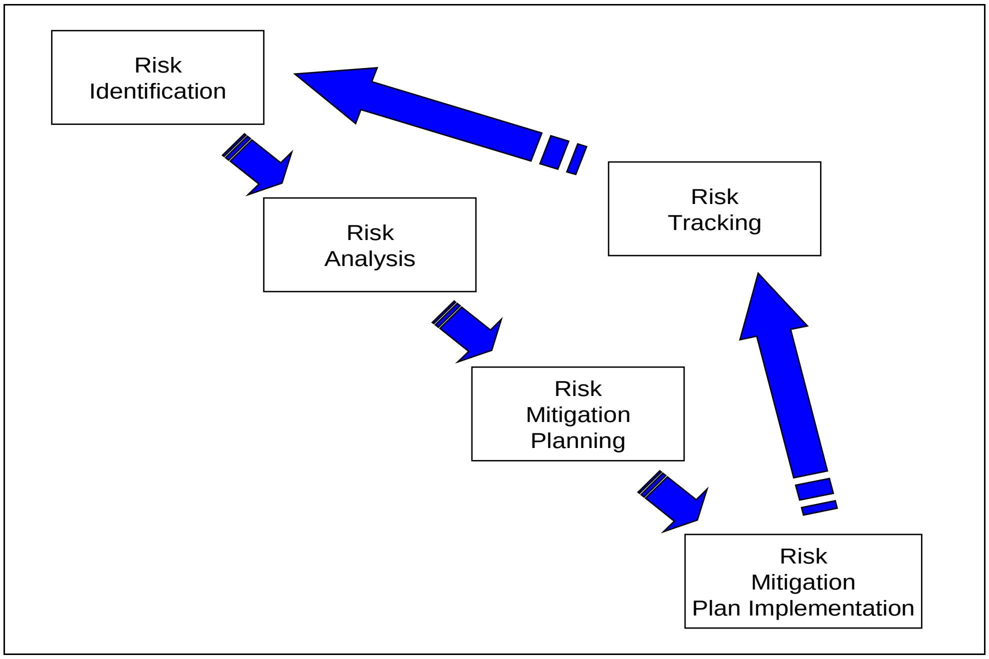

Figure 10. DoD Risk Management Process (From: [22, p. 4])

D. RISK KEY ACTIVITIES

Quantifying risk is the process of identifying all potential future uncertainties (i.e., likelihoods and consequences) associated with a particular program's success or failure criteria. It also examines each element of a program to determine associated root causes [22, p. 7].

Risk analysis is the process of using a systems framework to account for uncertainties in modeling, behavior, prediction models, interaction among components of a system, and impacts on the system and its surrounding environment [24]. The intent of risk analysis is to determine the severity of risk by the following.

- considering the likelihood of the root cause occurrence
- identifying the possible consequences in terms of performance, schedule, and cost
- identifying the risk level using the Risk Reporting Matrix shown in Figure 11.

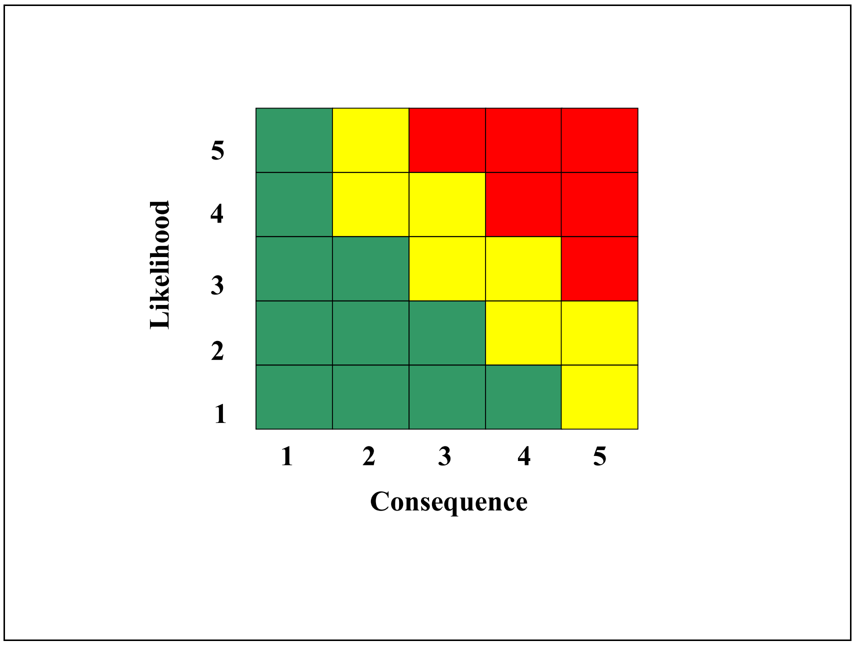

Figure 11. Risk Reporting Matrix (From: [22, p. 11])

The Risk Reporting Matrix above is used to determine the level of risks identified within a program. The level of risk for each root cause is reported as low (green), moderate (yellow), or high (red). The level of likelihood of each root cause is established using the specified criteria below (Figure 12).

Likelihood

Level	Likelihood	Probability of Occurrence
1	Not Likely	~10%
2	Low Likelihood	~30%
3	Likely	~50%
4	Highly Likely	~70%
5	Near Certainty	~90%

Figure 12. Levels of Likelihood Criteria (From: [22, p. 12])

The level and types of consequences of each risk are established utilizing criteria described in Table 1.

Consequence

Level	Technical Performance	Schedule	Cost
1	Minimal or no consequence to technical performance	Minimal or no impact	Minimal or no impact
2	Minor reduction in technical performance or supportability, can be tolerated with little or no impact on program	Able to meet key dates. **Slip < * month(s)**	Budget increase or unit production cost increases. **< ** (1% of Budget)**
3	Moderate reduction in technical performance or supportability with limited impact on program objectives	Minor schedule slip. Able to meet key milestones with no schedule float. **Slip < * month(s) Sub-system slip > * month(s) plus available float.**	Budget increase or unit production cost increase **< ** (5% of Budget)**
4	Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success	Program critical path affected. **Slip < * months**	Budget increase or unit production cost increase **< ** (10% of Budget)**
5	Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success	Cannot meet key program milestones. **Slip > * months**	Exceeds APB threshold **> ** (10% of Budget)**

Table 1. Levels and Types of Consequence Criteria (From: [22, p. 13])

The results for each risk are then plotted in the corresponding single square on the Risk Reporting Matrix [22, pp. 11-13].

Risk Mitigation Planning is a process of determining the proper action in addressing foreseen uncertainty. The intent of risk mitigation planning is to answer the question *"What is the program approach for addressing this potential unfavorable consequence?"* Mitigation options include the following.

- Avoiding risk by eliminating the root cause and/or the consequence
- Controlling the cause or consequence
- Transferring the risk, and/or
- Assuming the level of risk and continuing on the current program plan

Risk Mitigation Plan Implementation is the process of ensuring the execution of the appropriate prescribed mitigation strategy [22, p. 19].

- Determines what planning, budget, and requirements and contractual changes are needed
- Provides a coordination vehicle with management and other stakeholders
- Directs the teams to execute the defined and approved risk mitigation plans
- Outlines the risk reporting requirements for on-going monitoring
- Documents the change history

Risk Tracking is the iterative process of monitoring and adjusting as necessary an implemented mitigation plan. Its intent is ensuring successful risk mitigation. It answers the question *"How are things going?"* by the following.

- Communicating risks to all affected stakeholders
- Monitoring risk mitigation plans
- Reviewing regular status updates
- Displaying risk management dynamics by tracking risk status within an Risk Reporting Matrix
- Alerting management when risk mitigation plans should be implemented or adjusted

An event's likelihood and consequences may change as the acquisition process proceeds and updated information becomes available. Therefore, throughout a program, a program office should reevaluate known risks on a periodic basis and examine the

program for new root causes. Successful risk management programs include timely, specific reporting procedures tied to effective communication among the program team [22, p. 20].

E. CHAPTE R SUMMARY

This chapter discussed the concept of risk, its management, key activities, and application as a systematic approach to the expeditious and thorough evaluation of complex systems or systems of systems under various operational or extreme conditions.

Having established the purpose and context of risk management as a component of the systems engineering process, the next chapter presents an iterative system engineering approach beginning with a stakeholder analysis and functional decomposition of the main objective or goal, "Conduct RCOH."

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III. RCOH STAKEHOLDER ANALYSIS AND FUNCTIONAL DECOMPOSITION

A. INTRODUCTION

This chapter builds on the previous chapter by identifying significant graphical representations or entities of interest associated with an RCOH, as well as their impacts. For the sake of simplicity in describing an extremely complex evolution, this chapter will also illustrate a broad view analysis of how to organize and conduct an RCOH. Sections B and C define the terms stakeholder and stakeholder analysis. Section D demonstrates the risk management methodology in the structure of the systems engineering process by performing a functional decomposition of the goal “Conduct RCOH” to determine its primary functions. Section E describes seven major industrial components associated with an RCOH. Section F presents a process flow diagram and detailed description of how a RCOH is coordinated and conducted while Section G summarizes the chapter.

B. STAKEHOLDE R

A stakeholder is an organization, group, individual, or entity directly or indirectly affected by the advancement, stagnancy, success, failure, or cancellation of a particular program or system architecture.

C. STAKEHOLDE R ANALYSIS

Stakeholder analysis is the process of identifying specific organizations, businesses, communities, groups or individuals affected by the planning, funding, management, success, or failure of a particular project or event. The following entities shown in Figure 13 were identified by this research as major stakeholders in an aircraft carrier’s RCOH.

Figure 13. Stakeholder Analysis

1. Major Stakeholders Defined

a. President of the United States

As Commander and Chief of the United States Military forces, the President is overall responsible for ensuring that the National Security Strategy adequately provides the appropriate resources allocation for naval forces to perform and continue their function of force projection, sustainability, and technological advancement as well as dominance of the maritime domain.

b. Congress

As stewards of American taxpayer's resources, it is responsible for the legitimate appropriation and proper funding of all Department of Defense (DoD) approved programs.

c. Taxpayers

The taxation of the American people's income is a major source of the revenue controlled and distributed by Congress to fund all programs presented in the program objective memorandum (POM).

d. Defense Acquisition Executive (DAE)

It is responsible for identifying and prioritizing acquisition category, ACAT ID, programs such as RCOHs. The DAE is also the milestone decision authority for such programs.

e. Program Executive Office (PEO)

The PEO, PMS 250 is overall responsible to Congress for the proper planning, budgeting, and solicitation of resources to accomplish an RCOH. The PEO executes all headquarters-level responsibilities for the acquisition and lifecycle management of aircraft carriers. For a Ship Construction, Navy (SCN)-funded program such as an RCOH, the PEO reports to the Assistant Secretary of the Navy for Research, Development, and Acquisition. The PEO also reports to the Chief of Naval Operations (CNO) through the NAVSEA Commander for matters pertaining to in-service support. Under the PEO, the Aircraft Carrier Program Office (PMS 312) executes all PEO responsibilities pertaining to aircraft carriers, including design, construction, and maintenance. Management authority, including budgeting for RCOHs, is delegated to the assistant program manager for RCOHs (PMS 312D). PMS 312D either performs internally or manages all aspects of the RCOH from initial budgeting and work planning to execution and follow-up lessons learned, except those responsibilities under the cognizance of the Naval Nuclear Propulsion Program (NNPP) [9, pp. 5, 6].

f. Navy Nuclear Power Program (NNPP)

The NNPP exercises its responsibilities through the Director of the NNPP, within the Office of the CNO, and through the Deputy Commander of NAVSEA for Nuclear Propulsion (O8) (responsible for the technical aspects of the propulsion plant). NAVSEA O8 has the overall program management responsibility, including

identification of budget needs for the nuclear work in the RCOH. The Deputy Administrator for Naval Reactors is responsible for reactor safety. The NNPP has their own staff of engineering and management personnel who manage their portion of the program. Some other key NNPP facilities that serve RCOHs include the following.

- Knolls and Bettis Atomic Power (Two government-owned, contractor-operated (GOCO) Department of Energy laboratories)
- A GOCO procurement organization devoted to acquiring certain NNPP materials needed to conduct the RCOH
- A specialized office within the Naval Supply Systems Command utilized for acquiring and supplying consumable materials needed for maintenance of NNPP hardware
- A planning capability designated the Carrier Reactor-Plant Planning Yard (RPPY), operated by NGC, which performs much of the RCOH planning for nuclear work, including development of the nuclear work package, known as the carrier reactor-plant overhaul package (CARPOP)

To implement its safety responsibilities, the NNPP maintains Department of Energy field offices (Naval Reactors Representative's Office (NRRO)) at nuclear-capable shipyards. At NGC, this office monitors work aboard the RCOH ship to ensure that it is conducted in a manner that assures the continued safe maintenance, repair, and subsequent operation of the ship's reactor plants. The NNPP has access to all NAVSEA offices on matters that interface between nuclear and non-nuclear responsibilities. It also has access to NNS on technical issues, indirectly by way of PMS 312D and directly from its own technical staff. In regards to safety matters, it has access to the yard by way of the NRRO [9, pp. 6, 7].

g. Naval Sea Systems Command (NAVSEA)

NAVSEA is responsible for contract administration and day-to-day management of the RCOH's execution phase via SUPSHIP NN. SUPSHIP NN, Code 152, holds the primary responsibility of ensuring that the shipyard complies with the established contract and that issues are identified and resolved quickly. Other SUPSHIP NN offices provide services to the supervisor or to PMS 312D when tasked. These services include but are not limited to work planning, financial-report review, non-

nuclear engineering, design review, quality assurance, government furnished material procurement and management, and financial management. The Code 1800 group in SUPSHIP NN supervises the planning of the RCOHs [9, p. 8].

h. Program Manager (PM)

The program manager or Sponsor, PMS 312D is directly responsible to PEO for the proper, oversight, schedule integration and adherence, resource management, and conflict resolution during the planning and execution phase of an RCOH.

i. United States Navy (USN)

The USN is the customer during an RCOH. It is responsible for ensuring that all carrier assets are available when necessary to support the National Security and Defense Strategy.

j. Ship's Force (SF)

The SF or crew refers to the labor force, operators, and inhabitants of a carrier before and after a RCOH. They perform various functions during the RCOH, including but not limited to the following.

- General watchstanding and oversight of the various compartments and spaces on the ship
- Safety aspects of work, including closing of valves and circuit breakers (referred to as "tagouts")
- Ship security
- Operation of shipboard equipment
- Damage Control (immediate response to fire or flooding)
- Training to support crew certification at delivery
- Maintaining ship cleanliness
- Logistics support, including records updating
- Ship administration

The crew also is responsible for the administration and execution of the ship's force work package (a set of tasks in the overall work package designated specifically for SF accomplishment). Some of these tasks include the repair of ship systems and the refurbishment of hundreds of onboard living spaces [9, p. 9].

k. Northrop Grumman Corporation (NGC)

Northrop Grumman Corporation (NGC) is the Lead Maintenance Activity (LMA) during an RCOH. It is also the major epicenter of naval military industrial work in Newport News, Virginia. NGC's role is to develop and implement the management tools required to establish, maintain, and disseminate an Integrated Master Schedule (IMS) and associated metrics or agendas during RCOH. It is the largest shipbuilder in the United States in terms of both facilities and employment and is the only U.S. shipyard with the capability to build and refuel nuclear aircraft carriers. Additionally, NGC is the planning yard for the nuclear portion of a RCOH [9, pp. 8, 9].

l. Customer Contracted Teams (CCT)

A CCT is a military, government, or contracted activity uniquely trained to accomplish specialized alterations, installations or repairs outside the scope but under the cognizance of the prime contractor.

m. Supervisor of Shipbuilding Newport News, Virginia (SUPSHIP NN)

SUPSHIP NN, the Naval Supervising Authority (NSA), provides the government oversight and contractual management of NGC during the planning and execution phases of an RCOH. The NSA is the single naval activity responsible for work being accomplished on carriers during RCOHs. It is responsible for ensuring that planned work is authorized for accomplishment and that the LMA complies with the established contract. Additionally, the NSA is the technical and contracting authority.

n. Type Commander (TYCOM)

The TYCOM has administrative control over an aircraft carrier and is responsible for a vast majority of lifecycle maintenance done on the ship outside of an RCOH. Additionally, it is responsible for ensuring that the ship deploys fully trained and prepared for her operational commitments [9, p. 10].

o. Elected Officials of Virginia

These official are representatives (i.e., mayor, governor, senators) elected by the citizens of Virginia to ensure the economic stability, industrial growth, infrastructure development/enhancement, and proper policy needed to optimize the productivity and value of the providences under their purview.

p. Opposition

Opposition is a rival military entity or naval force responsible for generating countermeasures against a Carrier Strike Group (CSG).

q. Environmentalists

Environmentalists are individuals or organizations dedicated to the sustainable and responsible management of all earthly resources. They advocate the stewardship of the global ecosystem through legislation, political influence, or changes in corporate as well as individual behavior.

r. Combatant Commanders (CCDR)s

Combatant Commanders are high-ranking military officials responsible for the prudent deployment of appropriate and available military assets within a specific geographical region for particular mission functions.

D. FUNCTIONAL DECOMPOSITION

A functional decomposition is an iterative detailed analysis that reduces a complex system or system of systems down to its essential elements or core components. From these core components or functions, basic requirements can be generated to support

proposed system architecture. As illustrated in Figure 14, the six primary functions necessary to conduct an RCOH are to plan, communicate, budget, fund, execute, and manage the overhaul. Each primary function is decomposed further for a detailed understanding of the intricacies involved in the evolution.

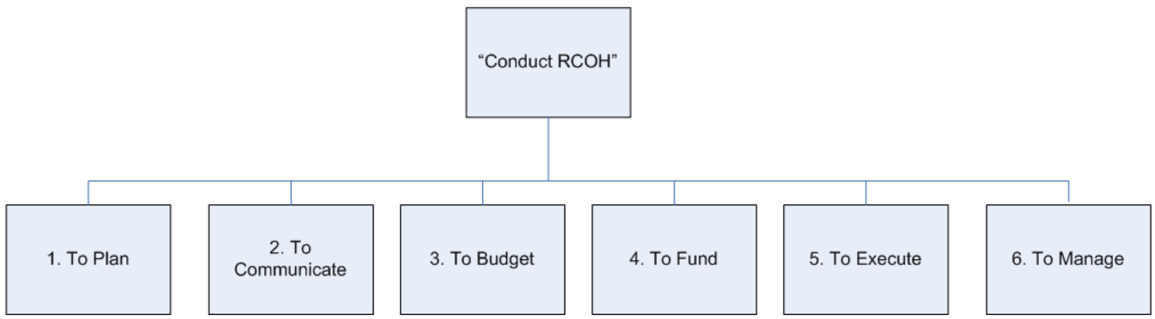

Figure 14. Top-level Functional Decomposition of "Conduct RCOH."

1. To Plan

Shown in Figure 15, To Plan is the most critical function in an RCOH. It is the precursor to a successful overhaul because (if initiated efficiently) it provides a reasonably detailed, methodical, and systematic guide to appropriate scheduling, resource loading, and execution of maintenance. Planning involves teambuilding, understanding program constraints and limitations, defining all planned and unplanned maintenance to be conducted, work integration, and contract negotiations. There are alternative reductionist's views of "To Plan." While there are alternative reductionism's views of "To Plan," by aligning the afore-listed functions under the higher-level function of 'plan,' the primary emphasis is placed on contracting, since the majority of government activities are service acquisition related. Team building is the process of establishing open communication, transparency, and stakeholder participation. Understanding program constraints requires conducting a risk analysis, forecasting future environmental impacts, and ensuring available technical expertise. Defining work is the process of understanding requirements, reviewing historical documentation, and consulting with subject matter experts. Integrating work involves receiving statements of work (SOW),

developing work breakdown structures (WBS) and generating an integrated master schedule (IMS). Finally, contract negotiations require submitting requests for proposals (RFP), proposal evaluations, and source selection.

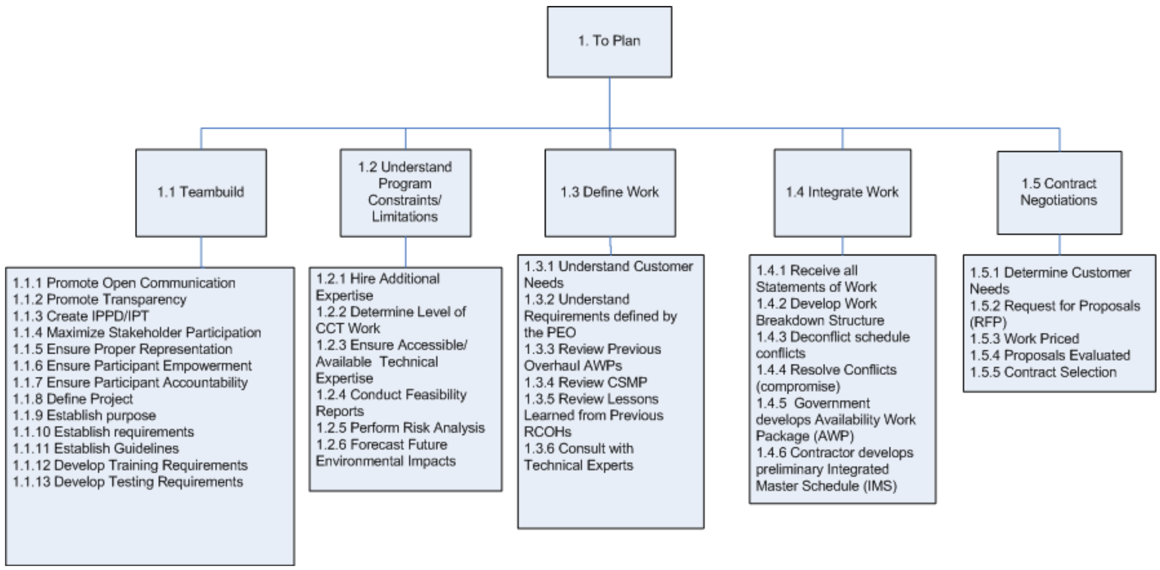

Figure 15. Functional Decomposition of "Plan."

2. To Communicate

Shown in Figure 16, To Communicate is the common denominator and essential capability connecting all functions. It is the process of delivering and organizing a message, transferring emotion as well as thought. Delivering a message involves a receiver, delivery media, and language. Organizing a message requires collecting, processing, and discarding any unnecessary data. Transferring emotion is the process of generating, processing, and releasing feelings. Lastly, transferring thought is characterized as organizing, choosing a position, and delivering thought.

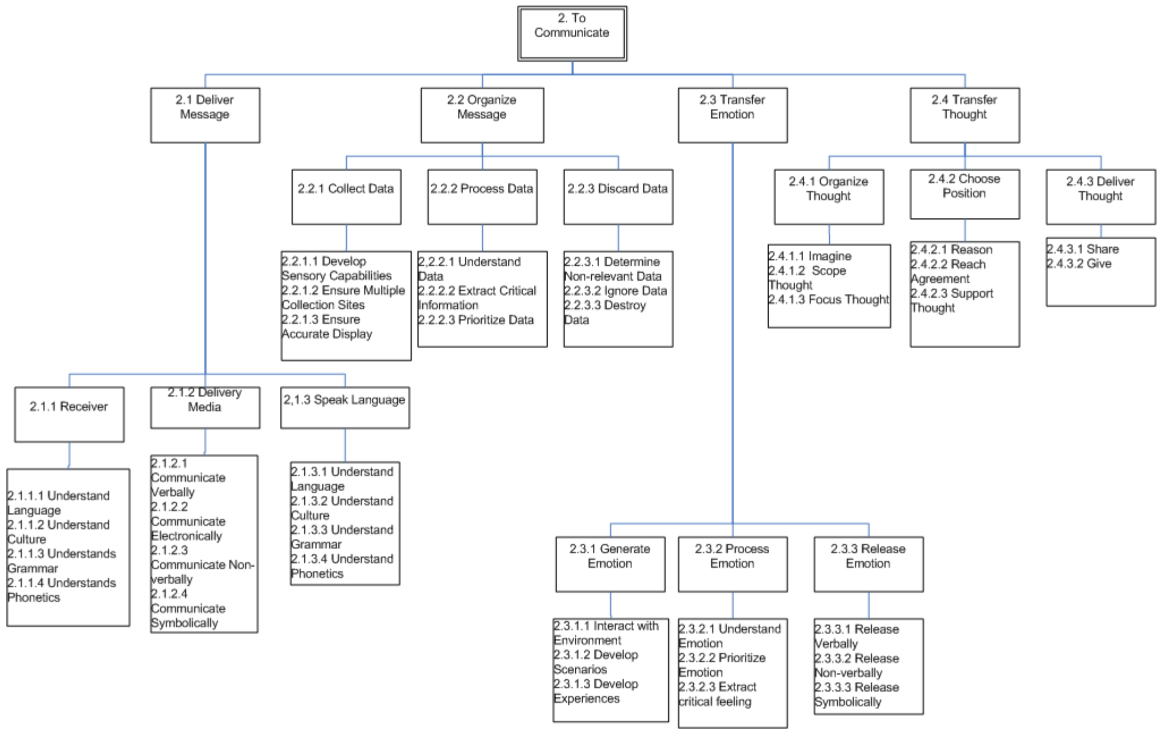

Figure 16. Functional Decomposition of Communicate.

3. To Budget

Shown in Figure 17, To Budget is providing appropriate monetary resources to ensure the overhauls' sufficient planning, scheduling, and execution. It is the process of prioritizing maintenance needs, selecting work to be accomplished, determining maintenance providers, estimating total cost, negotiating contract costs, and requesting funds from Congress. Prioritizing maintenance needs involves reviewing proposed maintenance, determining essential mission capabilities, and reviewing historical data. Selecting work to be accomplished involves scoping work, determining required maintenance, and de-scoping work. Determining a maintenance provider is deciding whether NGC, CCT, SF or a combination of those groups will conduct ship repairs, modifications, or alterations. Cost Estimation entails conducting an independent cost estimate, a cost benefit analysis, and a program manager's cost estimate to forecast the expected cost of an overhaul. Negotiating contract cost is reaching an agreement between

the contractor and government as to the appropriate total cost of the overhaul. Finally, presenting the cost before Congress is the process of requesting appropriations to fund the overhaul.

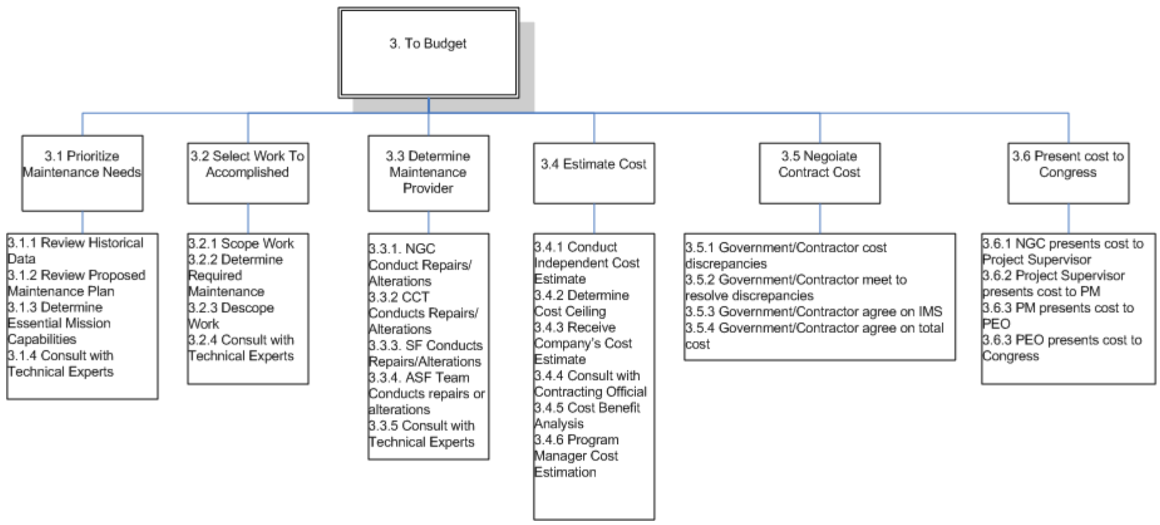

Figure 17. Functional Decomposition of Budget.

4. To Fund

Shown in Figure 18, To Fund is the action of monetarily compensating an entity for providing a service. It involves obtaining, appropriating, and distributing resources. Obtaining resources is accomplished by submitting a budget request for approval to Congress. Appropriating resources or apportionment is the process of Congress itemizing funds into specific accounts (colors of money) and authorizing it to the Program Managers Office (PMO). Paying the contractors refers to the government making a commitment, obligation, expenditure, and outlay to the contractor. Additionally, fees are calculated at the end of the overhaul.

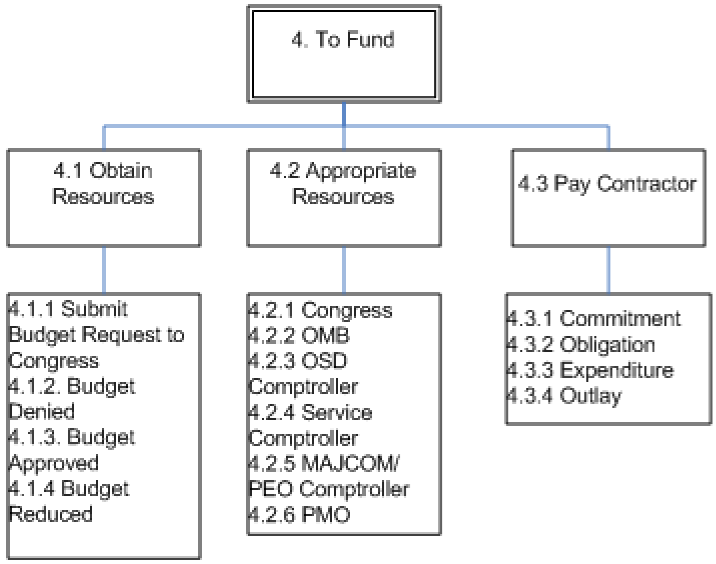

Figure 18. Functional Decomposition of Fund.

5. To Execute

Shown in Figure 19, To Execute is the process of government and contractor initiating authorized maintenance, repairs, alterations associated with the RCOH. It is instituted by a finalized authorized work package (AWP) and integrated master schedule (IMS), and by conducting scheduled maintenance. Preparing a finalized AWP involves the PMO formalizing the work to be completed during the RCOH. The IMS created and maintained by the contractor contains the work breakdown structures (WBS) of all entities authorized to complete maintenance during the overhaul. Finally, conducting maintenance is the deck-plate wrench turning and government oversight associated with an overhaul.

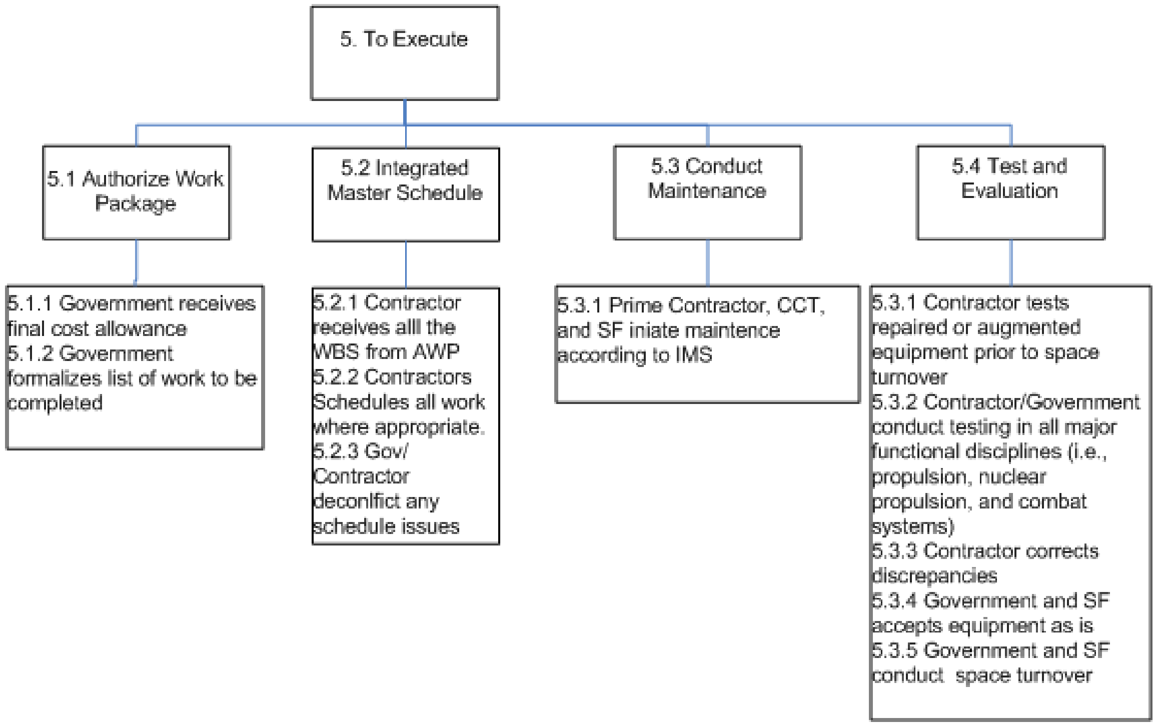

Figure 19. Functional Decomposition of Execute.

6. To Manage

Shown in Figure 20, To Manage is the process of handling or directing a system efficiently and appropriately towards achieving its main objectives while displaying some level of professional expertise. It involves leading, synchronizing, commanding and controlling an organization or group. Leadership requires organizing and performance. Synchronization includes motivation, training, and hiring appropriately. Commanding entails communicating expectations, managing resources, and establishing a hierarchy. Additionally, control refers to the responsibility of correcting discrepancies, monitoring performance, and setting up processes.

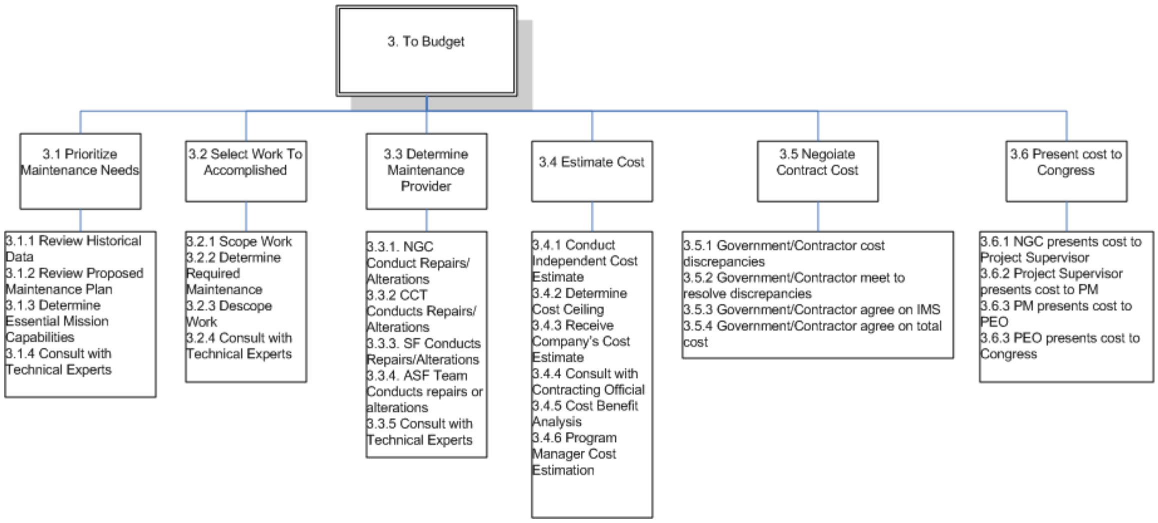

Figure 20. Functional Decomposition of Manage.

E. SEVEN INDUSTRIAL COMPONENTS OF AN RCOH

According to Mr. Richard MacPherson, the SUPSHIP NN RCOH Planning Manager, an RCOH is comprised of seven different industrial components planned by the PMO to accomplish specific types of maintenance during the overhaul. As shown in Figure 21, the seven main industrial categories are Nuclear Propulsion, Topside, Non-Nuclear Propulsion, Hull Mechanical and Electrical (HM&E), Combat Systems (CS/C4I), Customer Contracted Teams (CCT), and Emergent and Supplemental (E&S) maintenance. Figure 21 presents a broad overview of the major industrial components of an RCOH. It is a notional illustration of the general weights assigned to each RCOH component and is not to be viewed as an exact description since each aircraft carrier's maintenance profile is unique.

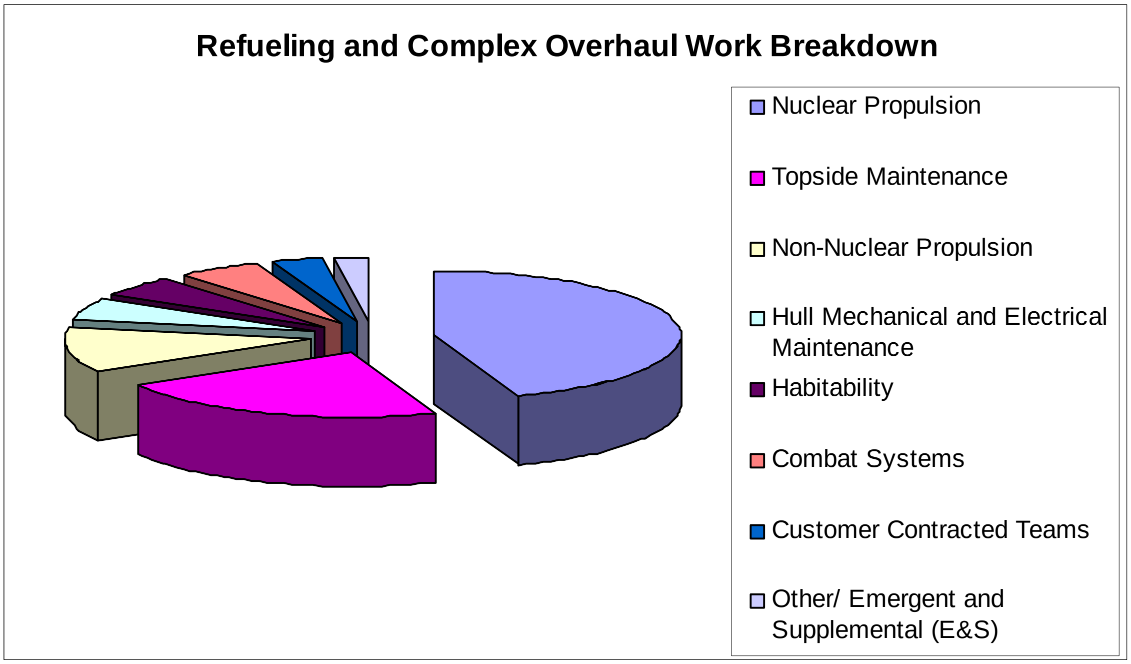

Figure 21. Refueling and Complex Overhaul Pie Chart

Nuclear propulsion maintenance applies to all repairs, modifications, alterations or installations directly associated and specifically designated for the overhauling, repairing, and refueling of an aircraft carrier's nuclear reactors. The major contributing factor to the successful completion of an RCOH and carrier delivery is the full accomplishment of its nuclear propulsion work package. Due to its mean time to refuel, material sensitivity, and classified nature, the nuclear propulsion work package constituents the critical path maintenance during an RCOH. All other maintenance efforts are integrated in a manner that minimally interferes with the successful completion the CARPOP. Also, the nuclear propulsion work package is the most militarily sensitive, costly, and heavily scrutinized segment of an RCOH.

Topside maintenance refers to any repairs, modifications, or alterations conducted outside the propulsion plant, internal as well as external to the ship. This work encompasses collecting holding and transfer (CHT) piping, deck machinery, and auxiliary system repairs as well as flight deck catapult and arresting gear upgrades. Some topside work can also be classified as mission-essential.

Non-Nuclear propulsion maintenance consists of all repairs, modifications, alterations, or installations of equipment, systems or sub-systems associated with ship propulsion while free of nuclear components or interferences. Although propulsion related, this work is conducted outside the cognizance or scope of the Naval Reactors Office (NRO).

Hull, Mechanical & Electrical (HM&E) maintenance refers to repairs, modifications, alterations and installations that support the solid mechanics, structural integrity, structural dynamics, computational mechanics, dynamics of electric power networks and control and distribution of electric power systems throughout the ship.

Combat System maintenance mostly consists of modifications, alterations, installations, or upgrades of equipment, systems or sub-systems associated with command, control, communication, computing, and intelligence (C4I) components or modules that enable an aircraft carrier to lead in weapons systems, air operations, carrier air traffic control, strike operations, anti-submarine warfare, meteorology and oceanography technologies.

Customer Contracted Team (CCT) maintenance refers to repairs, modifications, alterations or installations conducted by an entity other than the prime contractor. They often but not always possess a level of expertise or critical skill set that is absent in the primary contractor. CCTs are often utilized when they possess the same skill set as the prime contractor but at lower overall cost. Currently, CCT maintenance represents a small overall portion of an RCOH authorized work package (AWP) but due to ever-present budget constraints, their workload and responsibilities are steadily increasing.

E&S maintenance refers to all repairs, modifications, alterations or installations not initially planned for by the PMO during an overhaul but authorized by the sponsor through a contract modification for accomplishment during an RCOH.

F. PROCESS FLOW DIAGRAM OF AN RCOH

The planning, organizing, and execution of an RCOH is one of the most challenging industrial and engineering undertakings of the Navy because of the massive

man-hours dedicated to scheduling, integrating, budgeting, and managing assigned work. Due to the enormity of this evolution, it is beyond the scope of this research to define all aspects of the overhaul fully; however, it does provide key processes that must occur for an RCOH to proceed. Figure 22 illustrates a general sequence of events or key processes that must occur to conduct an RCOH beginning with Congressional authorization.

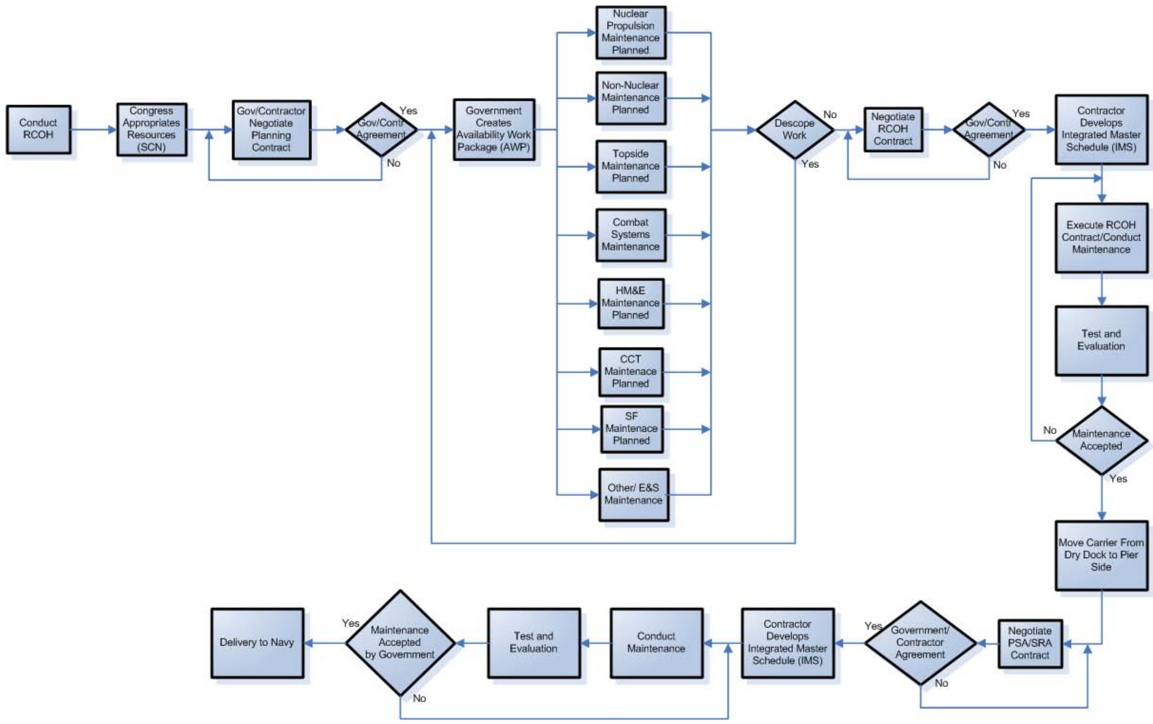

Figure 22. General Process Flow Diagram of an RCOH.

Congress reviews the President’s Budget and the Program Objective Memorandum (POM) to determine necessary fundable programs and their requirements. They then develop a cost estimate, apply appropriations and funding policies, budget using planning, programming, budgeting, and execution (PPBE), and appropriate through the enactment process. The enactment process involves legislation passing a budget resolution, authorization bill, and an appropriation bill. Afterwards, Congress provides budget authority to the Office of Management and Business (OMB), which apportions resources to the Office of the Secretary of Defense (OSD) Comptroller. The OSD Comptroller then releases those resources to the Service Comptroller, who in turn,

allocates funds to the Major Command/Program Executive Officer for Aircraft Carriers (MAJCOM/PEO Carriers). PEO Carriers then sub-allocates resources to the PMO to execute an RCOH [25].

Ship Conversion and Construction, New (SCN) pecuniary resources are appropriated and utilized during an RCOH. SCN funds have a programming lifecycle of five years and a maximum of five years for execution of funds by the project team (government and prime contractor) after being programmed. Once funding is secured, the project team begins negotiating a RCOH planning contract. The planning contract covers the expenses anticipated and required to begin the *planning phase* of an RCOH. After the project team reaches a contract agreement, the planning phase begins. The planning phase lasts three years and involves creating management strategies and guidelines, team building through integrated production teams (IPTs), allocating appropriate labor force to support planning efforts, developing an authorized work package (AWP) as well as a preliminary integrated master schedule (IMS).

The AWP is a database that comprises the entire work breakdown structures of the seven major industrial components described in Section E. It accounts for all of the routine and anticipated nuclear propulsion, non-nuclear propulsion, topside, combat systems, hull mechanical and electrical, customer contract team, ship force and emergent and supplemental maintenance supported for accomplishment during the RCOH. As the AWP is compiled, work is continually added or removed to support the obligated budget, or imposed monetary or schedule constraints. While the AWP is being generated, the LMA (prime contractor) simultaneously develops an IMS, which details the work authorized for accomplishment, the duration of the tasks, and the entity/entities accountable for performing the work. Upon completing the development of the AWP and IMS, the RCOH execution contract is negotiated.

The RCOH execution contract covers the anticipated expenses to be incurred during the *execution phase* of the overhaul. Upon an agreement reached by the government and prime contractor as to the terms and conditions set forth by the execution contract, physical labor begins. During this phase, all repairs, refurbishments, alterations, and installations are conducted in accordance with the AWP and IMS. One of the most

important evolutions during the execution phase is the separation of the ship into segments to support the removal, refurbishment, and replacement of the vessel's nuclear reactor. Additionally, all authorized work is monitored, de-conflicted, progressed, and reported by the project team to ensure cost and schedule adherence.

Upon completion of authorized maintenance tasks, the equipment, system, or sub-system are tested and evaluated to ensure that they meet the appropriate performance parameters. After completing the test and evaluation (T&E) phase, the government either accepts or rejects the maintenance accomplished by the LMA. If the maintenance is accepted, the government resumes ownership of the tested equipment, system, or subsystem; however, if the maintenance is not accepted, the contractor will continue to repair or modify the equipment until the appropriate performance standards are met.

Once the reactor is refueled, the ship reassembled, and the majority of maintenance completed, the carrier is removed from dry-dock and placed pier side. There it undergoes a post selective availability/selective restrictive availability (PSA/SRA) in which work that could not be accomplished during the RCOH is completed. The PSA/SRA differs from the RCOH in the scope of work planned for accomplishment and by the funding source. The PSA is funded with SCN dollars while the SRA is funded with operational maintenance, Navy (OM&N) resources. Additionally, the Type Commander, Commander Naval Air Force (COMNAVAIR/LANT) instead of the Program Executive Officer for Carriers (PMS 312D) is the sponsor.

G. CHAPTE R SUMMARY

This chapter began by describing the key players involved in an RCOH and how they either affect or are impacted by the overhaul. It then proceeded to decompose functionally the goal of conducting an RCOH into six primary functions: to plan, to communicate, to budget, to fund, to execute, and to manage. The six primary functions were further analyzed to provide a broad overview of what an RCOH required. From the "to plan" function, seven major industrial components were determined that characterized the planning phase of the RCOH. It was revealed that these major industrial complexes determined the type and scope of work accomplished during the overhaul. A process flow

diagram was then presented that illustrated the sequence of events necessary to coordinate and institute an RCOH effort starting with Congressional authorization to the aircraft carrier's redelivery to the Navy.

Having established the various entities involved in an RCOH, its (RCOH) primary functions, major industrial components, and sequence of events, the next chapter presents an iterative risk analysis within the structure of the systems engineering process.

IV. RISK ANALYSIS

A. INTRODUCTION

This chapter describes the most common risks associated with an RCOH beginning by defining the terms risk (Section B), risk identification (Section C) and root causes (Section D). It then determines the possible risks (Section E) associated with the primary functions (Chapter III) of conducting an RCOH. Using the risk likelihood table provided in Chapter II, it performs a risk analysis (Section F) by assigning weights (i.e., degrees of likelihood and severity) to each risk. Section G uses the software application program Probability/Consequences and Schedule to construct a risk matrix from which are exposed the most urgent risks anticipated to (1) negatively impact each primary function of an RCOH as well as (2) the overhaul in the totality of functions. Section H concludes with a summary of the chapter.

B. RISK DEFINED

"Risk is the unknowable seemingly captured through logic and reason. It is the likelihood of occurrence convolved with the commensurate consequence of that occurrence. Risk is therefore both subjective and quantifiable. It is subjectivity by our inability to determine full causality of future events [26]." According to Professor Gary Langford, Systems Engineering Professor at the Naval Postgraduate School, risk is quantifiable by one's determination to understand the set of initial conditions, the problem, and the solution, that is through a theory of consequences. Simple risk is the multiplication of two quantities, the consequence of the performance of a function and the likelihood of that consequence occurring. The consequence of performance of a function is defined as the suspected or unsuspected outcome of an event predicated by a specific course of action or inaction. The likelihood of a consequence occurring is the probability of a suspected or unsuspected event actually taking place. It enables the estimation of unknown parameters based on known outcomes.

C. RISK IDENTIFICATION

As described in Chapter II, *risk identification* is the first key activity in the risk management process. It is the dynamic, imaginative, and iterative process of accessing the future or current risks of a program, program element, system, sub-system, or event by brainstorming, forecasting, or analyzing historical data to isolate root causes and begin developing mitigation and planning strategies [22, p. 7]. The intent of risk identification is to answer the following basic questions.

- What can go wrong?
- When can it go wrong?
- Where can it go wrong?
- How can it go wrong?
- Why can it go wrong?
- What is the impact or consequence if it goes wrong?
- What is the likelihood that it will go wrong?

D. ROOT CAUSES

Root causes are those potential unknown events that adversely affect a program's success if they occur at any time in its lifecycle [22, p. 8].

E. IDENTIFIED RISKS

As explored in the previous chapter, the six primary functions necessary to conduct an RCOH are to plan, communicate, budget, fund, execute, and manage the overhaul. Each function has been evaluated to determine the potential risks that can deter a project team's ability to meet its overall cost, schedule and performance goals. The risks presented by this research are not all inclusive; however, through private telephone interviews with key personnel from SUPSHIP NN (i.e., CVN 70 Project Supervisor, RCOH Maintenance Planning Manager, Code 180 (Contracting Department), and Code 152 (Waterfront Operations Department)), they represent a conservative view of those risks as well as trends historically associated with an RCOH. Having only a minimal number of data points to extract from, this research assumes that the information provided below is accurate.

1. **To Plan.** The risks associated with the planning function of an RCOH (Figure 14) include but are not limited to:

1) Large amounts of unidentified work discovered necessary for accomplishment during the overhaul

Likelihood

Level 4, Highly Likely

≈70% Probability of Occurrence

Consequence of Occurrence

Cost – Level 2, Budget increase by < 3% of budget

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 2, Minor reduction in supportability, can be tolerated with little or no impact on program objectives.

2) Identified work not properly scheduled and integrated

Likelihood

Level 2, Low Likelihood

≈30% Probability of Occurrence

Consequence of Occurrence

Cost – Level 2, Budget increase by < 3% of budget

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 3, Moderate reduction in technical performance or supportability, can be tolerated with little or no impact on program objectives.

3) Lack of subject matter expertise during planning phase (government)

Likelihood

Level 1, Not Likely

≈10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5% of budget

Schedule – Level 4, Program critical path may be affected.

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

4) Government technical requirements modification

<u>Likelihood</u>

Level 4, Highly Likely

≈70% Probability of Occurrence

<u>Consequence of Occurrence</u>

Cost – Level 4, Budget increase by < 10% of budget

Schedule – Level 4, Program critical path may be affected.

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

5) Meeting inundation

<u>Likelihood</u>

Level 1, Not Likely

≈10% Probability of Occurrence

<u>Consequence of Occurrence</u>

Cost – Level 2, Budget increase by < 1% of budget

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 2, Minor reduction in technical performance or supportability, can be tolerated with little or no impact on program.

6) Ineffective IPTs due to unempowered decision makers

<u>Likelihood</u>

Level 3, Likely

≈30% Probability of Occurrence

<u>Consequence of Occurrence</u>

Cost – Level 1, Minimal or no impact

Schedule – Level 2, Able to meet key dates.

Performance – Level 3, Moderate reduction in technical performance or supportability, can be tolerated with little or no impact on program objectives.

7) Lack of formalized processes and strategies

Likelihood

Level 2, Low Likelihood

$\approx$30% Probability of Occurrence

Consequence of Occurrence

Cost – Level 1, Minimal or no impact

Schedule – Level 2, Able to meet key dates.

Performance – Level 1, Minimal or no consequence to technical performance.

8) Lack of process standardization from one project to the next

Likelihood

Level 3, Likely

$\approx$50% Probability of Occurrence

Consequence of Occurrence

Cost – Level 1, Minimal or no impact

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 1, Minimal or no consequence to technical performance.

9) Lack of learning curve experienced by mentored(military) personnel providing government oversight

Likelihood

Level 1, Not Likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 2, Budget increase by < 1%

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 1, Minimal or no consequence to technical performance.

10) Lack of information transparency

Likelihood

Level 2, Low Likelihood

$\approx$30% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 1, Minimal or no consequence to technical performance.

11) Inexperienced project team leadership (government)

Likelihood

Level 4, Highly Likely

$\approx$70% Probability of Occurrence

Consequence of Occurrence

Cost – Level 5, Exceeds APB threshold

Schedule – Level 4, Program critical path affected.

Performance – Level 1, Minimal or no consequence to technical performance.

12) Low Motivation/Morale

Likelihood

Level 2, Not Likely

$\approx$30% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget increase or unit production cost increase

Schedule – Level 5, Cannot meet key program milestones

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

13) Ambiguous, incomplete, or erroneous AWP work items

Likelihood

Level 1, Not Likely

$\approx$5% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 2, Minor reduction in supportability, can be tolerated with little or no impact on program.

14) Erroneous IMS

Likelihood

Level 3, Likely

$\approx$50% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 2, Minor reduction in supportability, can be tolerated with little or no impact on program.

2. **To Communicate.** The risks associated with communicating (Figure 14) during RCOH include but are not limited to:

1) Misinterpretation of technical requirements

Likelihood

Level 1, Not Likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 2, Minor reduction in supportability, can be tolerated with little or no impact on program.

2) Inaccurate work progressing

Likelihood

Level 2, Highly Likely

$\approx$70% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 1, Minimal or no consequence to technical performance.

3) Unperformed scheduled work

Likelihood

Level 1, Not Likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 1, Minimal or no consequence to technical performance.

4) Unresolved work overlap

Likelihood

Level 1, Not Likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

5) Adversarial relationship between government and contractor

Likelihood

Level 1, Not Likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget increase by < 10%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

6) Late material arrival

Likelihood

Level 2, Low Likelihood

≈30% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget increase by < 10%

Schedule – Level 5, Cannot meet key program milestones.

Performance – Level 4, Major shortfall in supportability; may jeopardize program success.

7) Union strike

Likelihood

Level 2, Low Likelihood

≈30% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget increase by < 10%

Schedule – Level 5, Cannot meet key program milestones.

Performance – Level 5, Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

8) Inadequate manpower resource loading

Likelihood

Level 4, Likely

≈70% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 4, Major shortfall in supportability; may jeopardize program success.

9) Misunderstanding of maintenance priorities by contractor

Likelihood

Level 1, Not Likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

10) Decreased safety awareness in shipyard

Likelihood

Level 1, Not Likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Major schedule slip. Program critical path may be affected.

Performance – Level 4, Major shortfall in supportability; may jeopardize program success.

11) Inaccurate current ship maintenance project (CSMP) data

Likelihood

Level 4, Highly Likely

$\approx$70% Probability of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 1, Minimal or no consequence to technical performance.

3. To Bu dget. The risks associated with not properly budgeting (Figure 14) during an RCOH include but are not limited to:

1) Excessive inaccurate cost estimation

Likelihood

Level 1, Not Likely

≈10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 5, Exceeds APB threshold

Schedule – Level 1, Minimal or no impact.

Performance – Level 1, Minimal or no consequence to technical performance.

2) Improper cost control

Likelihood

Level 5, Highly Likely

≈70% Probability of Occurrence

Consequence of Occurrence

Cost – Level 5, Exceeds APB threshold

Schedule – Level 1, Minimal or no impact.

Performance – Level 1, Minimal or no consequence to technical performance.

3) Inadequate Budget

Likelihood

Level 4, Highly Likely

≈70% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Program critical path may be affected.

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

4) Improper of contract management

Likelihood

Level 1, Not Likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 5, Exceeds APB threshold

Schedule – Level 5, Cannot meet key program milestones.

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

5) Improper assessment of ship's material condition prior to RCOH beginning

Likelihood

Level 1, Not Likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 1, Minimal or no consequence to technical performance.

4. To Fund. The risks associated with funding (Figure 14) an RCOH include but are not limited to:

1) Late payments to contractor from government

Likelihood

Level 1, Not likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget increase by < 10%

Schedule – Level 4, Program critical path affected.

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

2) Program reprioritized

Likelihood

Level 3, Likely

$\approx$50% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget decrease by < 10%

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

3) Program cancellation

Likelihood

Level 1, Not likely

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 1, No impact

Schedule – Level 1, No impact

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

4) Countries national commitments (i.e., wars, housing market crisis, and financial rescue packages)

Likelihood

Level 3, Likely

≈50% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget decrease by < 10%

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

5) Prime contractor's economic stability

Likelihood

Level 1, Not Likely

≈10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget increase by < 10%

Schedule – Level 4, Program critical path affected.

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

5. To Execute. The risks associated with executing an RCOH include but are not limited to:

1) Schedule delay

Likelihood

Level 5, Near Certainty

≈90% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget increase by < 10%

Schedule – Level 4, Program critical path affected.

Performance – Level 3, Moderate reduction in technical performance or supportability, can be tolerated with little or no impact on program objectives.

2) Rework

Likelihood

Level 3, Likely

$\approx$50% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 3, Moderate reduction in technical performance or supportability, can be tolerated with little or no impact on program objectives.

3) Reduced manpower (government/contractor)

Likelihood

Level 4, Highly Likely

$\approx$70% Probability of Occurrence

Consequence of Occurrence

Cost – Level 2, Budget increase by < 1%

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

4) Loss of trade skills (contractor)

Level 3, Likely

$\approx$50% Probability of Occurrence

Consequence of Occurrence

Cost – Level 2, Budget increase by < 1%

Schedule – Level 3, Minor schedule slip. Able to meet key milestones with no schedule float.

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

5) Excessive occupational injuries

Likelihood

Level 1, Not Likely

≈10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 2, Budget increase by < 1%

Schedule – Level 4, Program critical path affected.

Performance – Level 4, Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success.

6) Unexpected hazards or natural disasters (i.e. nuclear spill, terrorist strike, major fire, flood, or act of god)

Likelihood

Level 1, Low Likelihood

≈20% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Program critical path affected.

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

6. To Manage. The risks associated with managing (Figure 14) an RCOH include but are not limited to:

1) Loss of all key management personnel

Likelihood

Level 1, Not Likely

≈10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 3, Budget increase by < 5%

Schedule – Level 4, Program critical path affected.

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

2) Unexpected mandated technical specifications (i.e., OSHA, NAVSEA)

Likelihood

Level 5, Near Certainty

$\approx$90% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget increase by < 10%

Schedule – Level 4, Program critical path affected.

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

3) Lack of team-building between government and contractor

Likelihood

Level 2, Low Likelihood

$\approx$30% Probability of Occurrence

Consequence of Occurrence

Cost – Level 1, Minimal or no impact

Schedule – Level 1, Minimal or no impact

Performance – Level 3, Moderate reduction in technical performance or supportability, can be tolerated with little or no impact on program objectives.

4) Lack of accountability (government/contractor)

Likelihood

Level 1, Low Likelihood

$\approx$10% Probability of Occurrence

Consequence of Occurrence

Cost – Level 4, Budget increase by < 10%

Schedule – Level 4, Program critical path affected.

Performance – Level 5, Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; will jeopardize program success.

F. RISK ANALYSIS

Risk analysis is the iterative process of actively considering the likelihood of the root cause occurrence, identifying the possible consequences in terms of performance, schedule, and cost and identifying the risk level using the Risk Reporting Matrix provided in Chapter II [22, p. 11]. The intent of risk analysis is to answer the following questions.

- How big is the risk?
- How often can it go wrong?
- How often does it go wrong?

G. RISK MATRIX

The following risk matrix, Figure 23, was compiled using the data from Section B and the technical expertise and guidance of various subject matter experts at SUPSHIP NN. Each risk was analyzed and evaluated based on their impact to the overall cost, schedule, and performance of the overhaul. Risks highlighted in green represent low-level risk events while yellow and red represent moderate to high-level risks events, respectively.

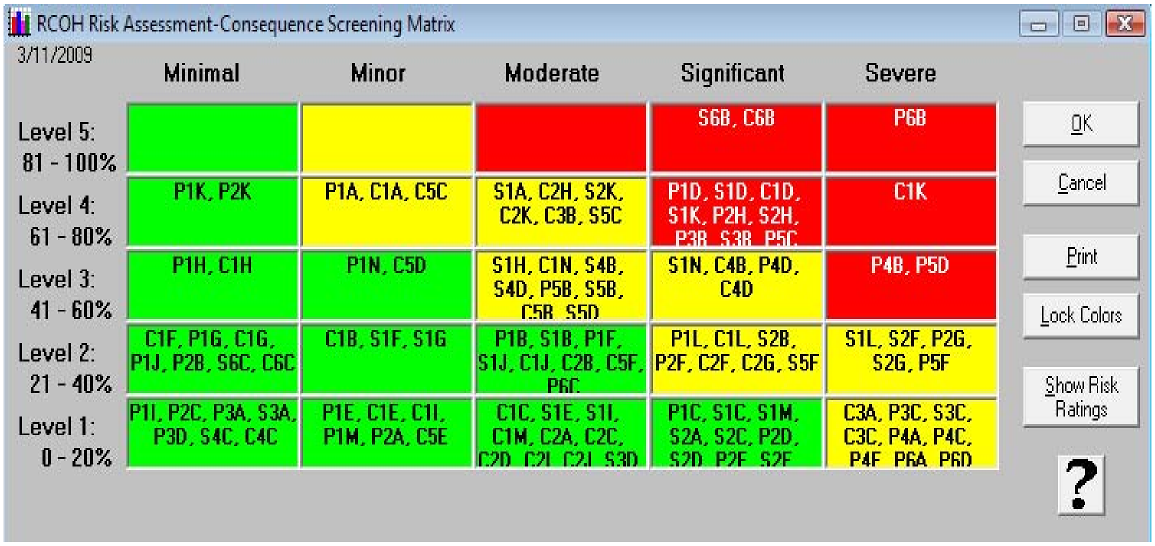

Figure 23. Comprehensive RCOH Risk Analysis – Consequence Screening Matrix

Legend

Prefixes:

C – Cost

S - Schedule

P - Performance

<u>Requirements and Risks:</u>

1. Effectively plan RCOH

1) 1A Large amounts of unidentified work discovered necessary for accomplishment during the overhaul.

2) 1B Identified work not properly scheduled and integrated.

3) 1C Lack of subject matter expertise during planning phase.

4) 1D Government technical requirements modification.

5) 1E Meeting inundation.

6) 1F Ineffective IPTs due to underpowered decision makers.

7) 1G Lack of formalized processes and strategies.

8) 1H Lack of process standardization from one project to the next.

9) 1I Lack of learning curve experienced by mentored personnel providing government oversight.

10) 1J Lack of information transparency.

11) 1K Inexperienced project team leadership (government).

12) 1L Low motivation/morale.

13) 1M Ambiguous, incomplete, or erroneous AWP work items.

14) 1N Erroneous IMS.

2. Effectively communicate during RCOH

1) 2A Misinterpretation of technical requirements.

2) 2B Inaccurate work progressing.

3) 2C Unperformed scheduled work.

4) 2D Unresolved work overlap.

5) 2E Adversarial relationship between government and contractor.

6) 2F Late material arrival.

7) 2G Union strike.

8) 2H Inadequate manpower resource loading.

9) 2I Misunderstanding of priorities.

10) 2J Decreased safety awareness.

11) 2K Inaccurate CSMP data.

3. Effectively budget an RCOH

1) 3A Excessive, inaccurate cost estimation.

2) 3B Inadequate budget.

3) 3C Lack of contract management.

4) 3D Improper assessment of ship's material condition.

4. Effectively fund RCOH

1) 4A Late payments to contractor from government.

2) 4B Program reprioritized.

3) 4C Program cancellation.

4) 4D Country’s national commitments.

5) 4E Prime contractor's economic instability.

5. Effectively execute RCOH.

1) 5A Schedule delay.

2) 5B Rework.

3) 5C Reduced manpower.

4) 5D Loss of trade skills.

5) 5E Excessive occupational injuries (contractor).

6) 5F Unexpected hazards or natural disasters.

6. Effectively manage RCOH

1) 6A Loss of all key management personnel.

2) 6B Unexpected mandated technical specifications.

3) 6C Lack of team-building.

4) 6D Lack of accountability.

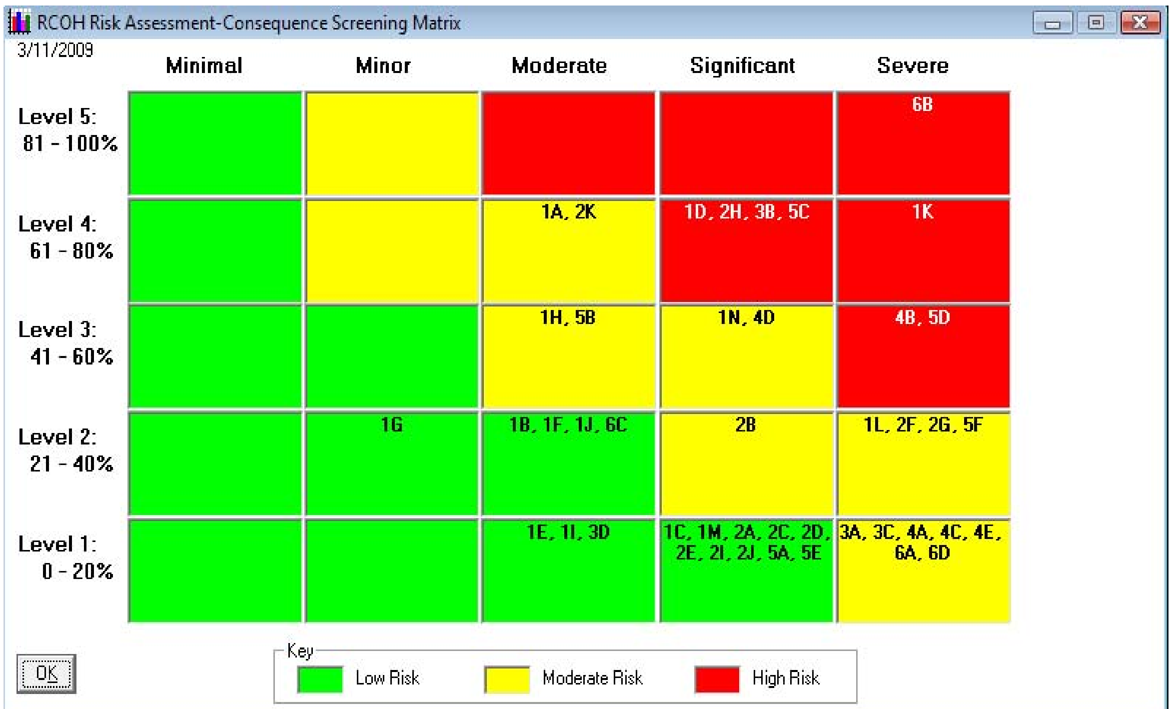

Figure 24. High Level RCOH Risk Analysis - Consequence Screening Matrix

Using data from Figure 23, Figure 24 is a condensed, top-level risk matrix constructed to highlight the risks possessing the greatest impact to an RCOH. Some of the low-level risks include meeting inundation (1E), identified work not properly scheduled and integrated (1B), and improper assessment of ship's material condition (3D). Some of the moderate level risks are inaccurate work progressing (2B), 1N erroneous integrated master schedule (IMS), and excessive inaccurate cost estimation. Finally, the high level

risks include unexpected mandated technical specifications (6B), government technical requirements modification (1B), inadequate manpower resource loading (2I), inadequate budget (3B), reduced manpower (5C), inexperienced project team leadership (1K), program reprioritized (4B), and the loss of critical trade skills (5D).

As previously stated in Section B, a consequence was the suspected or unsuspected outcome of an event predicated by a specific course of action or inaction. All of the aforementioned evaluated risks in their extreme and unmitigated cases resulted in the same two consequences. The two primary consequences were excessive cost overruns and schedule delay. The subsequent analysis and remainder of the chapter focused on developing risk mitigation strategies for the two primary consequences derived from Figures 23 and 24.

H. RISK MITIGATION STRATEGIES

Section G revealed various risks that could negatively influence the successful management and completion an RCOH; however, this research focused on the two main consequences of those evaluated risks. Those consequences were excessive cost overruns and schedule slippage.

Excessive cost overruns refer to the inability of an RCOH program to stay within its budgetary constraints due to improper cost control. Improper cost control describes the inability of a program office to manage the cost accounting, resource allocation and distribution, or earned value management of a project/program effectively. In earned value, excessive cost overruns occur when ACWP > BCWP at any given point in time on an earned value curve. ACWP is the actual cost of work performed and BCWP is the budgeted cost of work performed or the earned value (EV). In this case, cost efficiency is defined as the following.

Cost Efficiency/Cost Performance Index [27]

$$\mathbf{CPI = BCWP / ACWP} \qquad [4\text{-}1]$$

Excessive schedule slippage can lead to late delivery, which refers to the extension of an RCOH outside of its contracted timeframe. For example, an RCOH is planned as a 33 – 40 month overhaul; however, to date, no RCOH has been completed within its initial contracted timeframe. In earned value, excessive schedule slippage leads to schedule delay, which is expressed when BCWS < BCWP at any given point in time on an earl value curve. In this case, schedule efficiency is defined as the following.

Schedule Efficiency/Schedule Performance Index [27]

$$\mathbf{SPI = BCWP / BCWS} \qquad [4\text{-}2]$$

To address the aforementioned risks of excessive cost overruns and schedule slippage, this research proposes three strategies.

The first strategy was to make no changes to the current RCOH process. It assumes that the current method of planning and conducting an RCOH is the most efficient because it leverages the lessons learned from each previous attempt. The second strategy was to reduce, eliminate, and defer certain types of work performed during an RCOH while also applying schedule compression techniques. In this option, mainly critical path (with limited non-critical path) maintenance would be performed during an overhaul. The third strategy was to increase the power efficiency of a carrier's nuclear reactors with the goal of eliminating the need for refuelings.

I. CHAPTE R SUMMARY

Using the six main objectives to perform an RCOH derived from Chapter III, this chapter identified the risks associated with conducting an overhaul within the context of increasing cost and time effectiveness of a carrier's overhaul. The risks were evaluated through an assessment of likelihood and consequences, as well as impact to the cost, schedule, and performance as defined in Chapter II. From this assessment, the risks were divided into low, moderate, and high levels. Using the program Probability/Consequences and Scheduling, a matrix was constructed to determine the major risks that could adversely affect an RCOH. From this matrix, ten (10) risks were

determined that could jeopardize the successful administration and completion of an overhaul. Of the ten risks discovered, two were selected for further in-depth analysis. From these two risks, three mitigations strategies were introduced and explored in Chapter V.

V. RISK MITIGATION AND ANALYSIS OF ALTERNATIVES

A. INTRODUCTION

This chapter explores the three mitigation strategies derived at the end of Chapter IV. Section B, the first strategy, discusses how an RCOH is planned and executed and the implications associated with maintaining the current process. Section C discusses the impacts of reducing the scope of work in the availability work package (AWP) and conducting selected maintenance pier side as opposed to in dry-dock. Section D evaluates the strategy of increasing the energy efficiency of a carrier and Section E is an analysis of the alternatives. Section F summarizes the chapter.

B. STRATEGY ONE – ASSUME THE RISK

The first strategy is to assume the risk of excessive cost growth and schedule delay by maintaining the current process. It assumes that the current process for conducting an RCOH is the most realistic solution and practical application due to the complexity of the evolution. This strategy is also deemed most appropriate since it inherits and leverages the experiences as well as lessons learned from previous overhauls.

NGC is the only shipyard currently capable of building aircraft carriers in the United States and it has built all of the Navy's carriers to date. Although Norfolk Naval Shipyard and Puget Sound Naval Shipyard can refuel nuclear ships and have dry-docks large enough to hold aircraft carriers, they do not have the facilities to refuel Nimitz-class carriers, nor do they have the workforce to accomplish the majority of the non-nuclear repair work. Since it was impractical or possible to sustain multiple shipyards capable of constructing and refueling nuclear aircraft carriers, NGC emerged as the sole source for these product lines.

Due to the level of uncertainty associated with RCOHs, fixed-price contracts were not considered appropriate contract vehicles. This is because fixed-price contracts place all risk on the contractor, who then builds that risk into the contract price, potentially making RCOHs unaffordable. Instead, the standard type of contract typically chosen is a cost-type contract, with incentive fees.

The planning phase for an RCOH begins approximately five years prior to the start of the execution contract, with nominal schedule duration of 33 months. This five-year planning period may be accompanied by condition changes within the shipyard such as total workload and trade skills shifting or labor problems. Additionally, these changes could be precipitated by events external to the RCOH. "Planning is a complex process because it merges three different objectives that compete for available funding:

- Refueling, repairing, and upgrading the reactor plants and related systems (as set out in the nuclear work package).
- Installing new, more-modern capabilities such as sensors, communications systems, and weapons systems (the modernization package).
- Performing necessary repairs or replacements of other existing equipment and systems to restore their function (the repair package) [9, p. 13]."

Early estimates of the work to be accomplished are generated from the draft nuclear and modernization packages, coupled with approximations of the repair package. These estimates form the basis for preliminary budget estimates. Preparation of the contract work package does not begin until the completion of a baseline availability work package (AWP). This is followed by preliminary authorized AWPs at the 36-, 12-, and 8-month pre-execution windows [9, p. 20]. The authorized AWP is the focus of contract negotiations that ultimately leads to the negotiated contractor (NGC) work package and the ship's force (SF) work package.

Planning is complicated by several factors. First, the budget for the execution of an RCOH can suffer to fund other Navy commitments, and the resulting volatility in budget causes uncertainty in the planning process. Second, while planning proceeds, the ship being planned for is still operational. This limits the government's ability to disassemble and inspect equipment, and accurately assess repair needs. Third, the Navy often delays design decisions to incorporate the latest war fighting capabilities.

For nuclear work, NGC and NAVSEA O8 develop a carrier reactor-plant overhaul package (CARPOP) that specifies all of the work to be accomplished during the RCOH. The CARPOP is constructed from requirements in the Commissioned Surface Ship General Reactor Plant Overhaul and Repair Specifications and other standardized maintenance requirements imbedded in the Budgeting, Planning, and Contracting for the

RCOH technical documentation governing the operation and maintenance of the reactor plant and related systems. Also, some testing for potential nuclear (as well as non-nuclear) work is coordinated by SUPSHIP NN Code 1800 in accordance with the Carrier-Availability Planning System (CAPS) [9, pp. 20-21].

The modernization management plan (MMP) governs the development of the (non-nuclear) modernization package. Norfolk Naval Shipyard is the hull-planning yard for Nimitz-class ships and provides the lead design services to support the modernization package, and other communities [9, pp. 21-23].

Modifications to the contract work package (AWP) occur mostly during the execution phase of the RCOH. Many of the tasks in the basic work package involve opening and inspection of portions of the ship (i.e., tanks and voids) to determine whether repairs are necessary. Tasks not explicitly covered in the authorized work package are subject to change control. NAVSEA O8 manages changes to the nuclear work package, while changes to the modernization and repair work packages are subject to the requirements of the PMP. “Changes are classified into one of several possible levels of importance.

- Those affecting ship characteristics or delivery dates required approval by the CNO.
- Those having other “significant” or “adverse” effects required PMS 312 approval. SUPSHIP NN may have the authority to approve lesser changes. What constitutes a lesser change can vary over the course of an RCOH. Requests for changes typically originate at the shipyard level. NGC upon finding a problem not covered by the work package first decides whether to seek specific reimbursement for the extra work. If so, an inspection report (IR) is prepared for SUPSHIP NN, describing the nature of the problem. IRs are usually reviewed by SUPSHIP NN production controllers (PC) and assistant project officers (APO); called assistant project supervisors (APS) on CVN 70 RCOH. At the start of an RCOH, there are usually four APSs: nuclear, propulsion, hull/deck machinery/outfitting, and combat systems. For the last 18-months of the RCOH, this group is reduced to one APS for propulsion systems and one APS for everything else, each assisted by 5 to 10 PCs. The team determines whether the issue revealed in the IR is already covered by the work package (if so, no further contract action is necessary). If not, the APSs and SUPSHIP NN Engineering department determined whether the items should be fixed, and if so, who should do the work (i.e., NGC, SF or

> CCT); they also determined the implications regarding the contract. The criteria used for deciding is expert opinion, weighing how critical the work is, and its (work) cost estimation. If the team (APSs and PCs) agree that the IR issue needs to be addressed, a field modification requisition (FMR) is initiated. A FMR is the vehicle by which any additions to the authorized work package are made following issuance of the RFP. For example, on the CVN 68 RCOH, approximately 6,300 FMRs were issued. Each FMR leads negotiations between the NGC and SUPSHIP NN Contract Departments as to the cost of the task, a contract change specification (adding cost and potential time to the RCOH contract) or to funding via of a level-of-effort (LOE) set aside through the SVC or E&S pool [9, pp. 26-29]."

During an RCOH, the baseline contract is modified a number of times to include additional tasking and changes in the original plans and schedules. Some contract modifications involve adding funds to the basic contract while other modifications do not change the funding but change the distribution of funds within contract line-item numbers (CLINs). Also, some modifications change the scheduled completion date of an RCOH or modify tasks without any increase in funding requirements [9, p. 29].

Under the current process, no RCOH has been completed within its initial schedule and proposed budget. For example, the first award for the CVN 68 RCOH planning contract to NGC was for $2.85 million. It included eight contract line-item numbers for the start of advance planning and support for the RCOH. As additional advance-planning funds were authorized in successive fiscal years, the basic contract was modified a number of times to include additional tasks and funds. By the end of the planning stage, NGC had been awarded almost $400 million for planning and support of the RCOH. In addition, during the RCOH, a four-month long union strike caused the delivery date of the CVN 68 to be extended 80 days out from March 5, 2001, to May 24, 2001. The 80-day extension was necessitated by delays in performing propulsion-plant work that was on the critical path of the RCOH. The Navy approved the 80-day schedule delay [9, pp. 99-101] and the RCOH total cost was approximately $3.15 billion [14].

During the CVN 69 RCOH, the Navy reset the contract target cost from $1.36 billion to $1.49 billion at completion. The contract modification extended the end date of the USS Eisenhower RCOH by 11 weeks to November 6, 2004 and was implemented due to the realignment of work priorities to help assist with the completion of the USS

Enterprise's extended dry-docking selected restricted availability (SRA) [14]. The modification also addressed the unforeseen impact of Hurricane Isabel setting the final cost of the RCOH at approximately $3.18 billion [13].

A statistical analysis of RCOH data reveals the low likelihood of future successful programs. The equations below show the likelihood of a RCOH successfully completing based on the three previous attempts. Successfully completed is defined as an RCOH being accomplished within the parameters of its initial contract limits (i.e., below or within its contracted target cost and schedule). The conclusions extracted from these calculations are subjective due to the minimal amount of data points available for analysis; however, they provide a general impression of the difficulty of this event. For example, two RCOHs have been completed and one is nearing completion. Assuming that the CVN 70 will complete within its designated time frame (March 2009), the probability of an RCOH completing on schedule is 1/3 or 33%. Since there are 11 carriers in the Navy, and three have undergone overhauls, eight RCOHs remain. Assuming that each RCOH is independent, the likelihood that all remaining RCOHs will be completed successfully is 0%. The assumption of independence is based on a few conditions. First, each RCOH is comprised almost entirely of new management personnel (government). Second, the material condition of each carrier varies widely with near total dependence on its previous operational tempo. Third, the contract negotiations and responsibilities for each RCOH vary based on the needs of the Navy and its enterprise strategy. Therefore, the contracts for each RCOH are fundamentally different. For example, NGC was designated the lead maintenance activity (LMA) during the CVN 70 RCOH but not during the CVN 68 overhaul. Fourth, the external influences that affect each RCOH are different. For example, the CVN 68 RCOH was extended due to a 4-month long union strike while the CVN 69 overhaul was extended due to hurricane preparations.

$$P_{(Successful\ Completion)} = \left(\frac{1}{3}\right)^{8} = 0.00015$$

The likelihood of at least one in the remaining eight RCOHs completing successfully is 96%.

$$P_{(At\ least\ 1\ success\ in\ 8)} = 1 - \left(1 - \left(\frac{1}{3}\right)^8\right) = 0.96098$$

If assuming that the CVN 69 completed on schedule, the probability that the eight remaining overhauls will be completed successfully is 4%.

$$P_{(Successful\ Completion)} = \left(\frac{2}{3}\right)^8 = 0.03902$$

The likelihood of at least one in the remaining eight completing successfully is 99%.

$$P_{(At\ least\ 1\ success\ in\ 8)} = 1 - \left(1 - \left(\frac{2}{3}\right)^8\right) = 0.99984$$

Neglecting the influence of a learning curve, the data reveals that under the current process of conducting an RCOH, the probability of the successful completion of all eight remaining carrier overhauls is unlikely; however, it is certain that at least one will be completed within its initial contracted parameters. In a private interview with Dr. Samuel Buttrey, a Probability and Statistics professor at NPS, the following formula was proposed in an attempt to account for learning experienced from one project to the next.

$$P_{(Successful\ Completion)} = \beta_o + (1-\beta_o)(1-e^{-L_o t})$$

$$\beta_o = \frac{number\ of\ successful\ \mathrm{RCOHs}}{number\ of\ RCOHs}$$

$$L_o = amount\ of\ learning\ \exp erienced (\%)$$

$$t = number\ of\ RCOHs\ remaining$$

For example, in the Excel model shown below (Table 2), if the probability of the first three RCOHs completing successfully is 33% and the learning experienced between each overhaul is approximately 10%, then likelihood of the fourth trial completing successfully is 39%, the fifth 45% and so forth. Figure 25 illustrates that the highest probability for successful completion under the current process is roughly 70% during the eleventh RCOH. The amount of learning assumed is based on the reasonable ideology

that if an event is experienced more than once by human beings, there is an expected amount of growth or learning associated with that particular event; however, a method of accurately quantifying learning is beyond the scope of this research.

Starting Probability (Bo)	Trial (t)	P(Successful Completion)	Ship
0.33	3	0.33	CVN 70
Learning (Lo)	4	0.39	CVN 71
0.1	5	0.45	CVN 72
	6	0.50	CVN 73
	7	0.55	CVN 74
	8	0.59	CVN 75
	9	0.63	CVN 76
	10	0.67	CVN 77
	11	0.70	CVN 78

Table 2. Notional RCOH Forecast

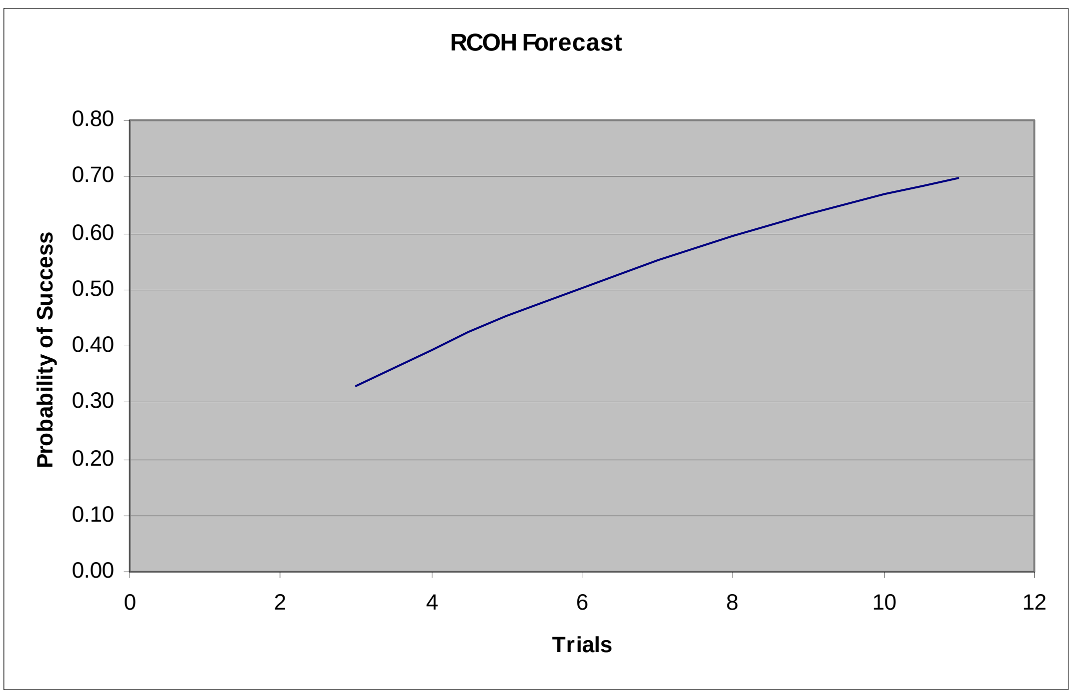

Figure 25. Graph of Notional RCOH Forecast

C. STRATEGY TWO – CONTROL AND TRANSFER THE RISK

The second strategy was to control and transfer the risk of historically increasing RCOH cost and schedule delay through work redistribution, cancellation, and deferment.

It (the strategy) relies on a functional area planners (FAP) keen understanding of the material condition of the ship, required maintenance schedule duration, and available resources. There are four types of maintenance applications of which an RCOH is comprised. They are preventative maintenance, performance based maintenance, condition based maintenance, and remedial maintenance.

Preventive maintenance (PM) is a schedule of planned maintenance actions aimed at the prevention of future failures. It is designed to preserve and enhance equipment reliability by replacing worn components before they actually fail. Preventive maintenance activities include equipment checks, partial or complete overhauls at specified periods, oil changes, lubrication and so on. In addition, workers can record equipment deterioration so they know to replace or repair worn parts before they cause system failure [28].

Performance based maintenance (PBM) defines the minimum maintenance conditions that have to be met through observational measures to sustain a piece of an equipment's or systems adequate operational usage [29].

Condition based maintenance (CBM) is an attempt to maintain the right equipment at the right time. It is based on using real-time data to prioritize and optimize maintenance resources. Observing the state of the system is known as condition monitoring. Such a system will determine the equipment's health, and act only when maintenance is actually necessary. Development in recent years have allowed extensive instrumentation of equipment, and together with better tools for analyzing condition data, the maintenance personnel of today are more than ever able to decide what is the right time to perform maintenance on some piece of equipment. Ideally condition based maintenance will allow the maintenance personnel to do only the right things, minimizing spare parts cost, system downtime and time spent on maintenance [30].

Corrective maintenance (CM) is maintenance performed as required, on an unscheduled basis, by the contractor following equipment failure. It provides a procedure of repairing components or equipment as necessary either by on-site repair or by replacing individual elements to keep the system in an adequate state of operation [31].

According the SUPSHIP NN RCOH Planning Manager, most work planned during an overhaul is categorized as preventive while additional work added to the contract through the IR and FMR process is corrective based.

Reducing the scope of work in the RCOH work package involves limiting an RCOH to only essential preventive, performance based, condition based, and corrective maintenances. In the context of this research, essential is defined as nuclear and limited non-nuclear work since the critical path of an RCOH is the nuclear propulsion repairs and refueling [32]. Figure 26 displays an example of an RCOH key event schedule.

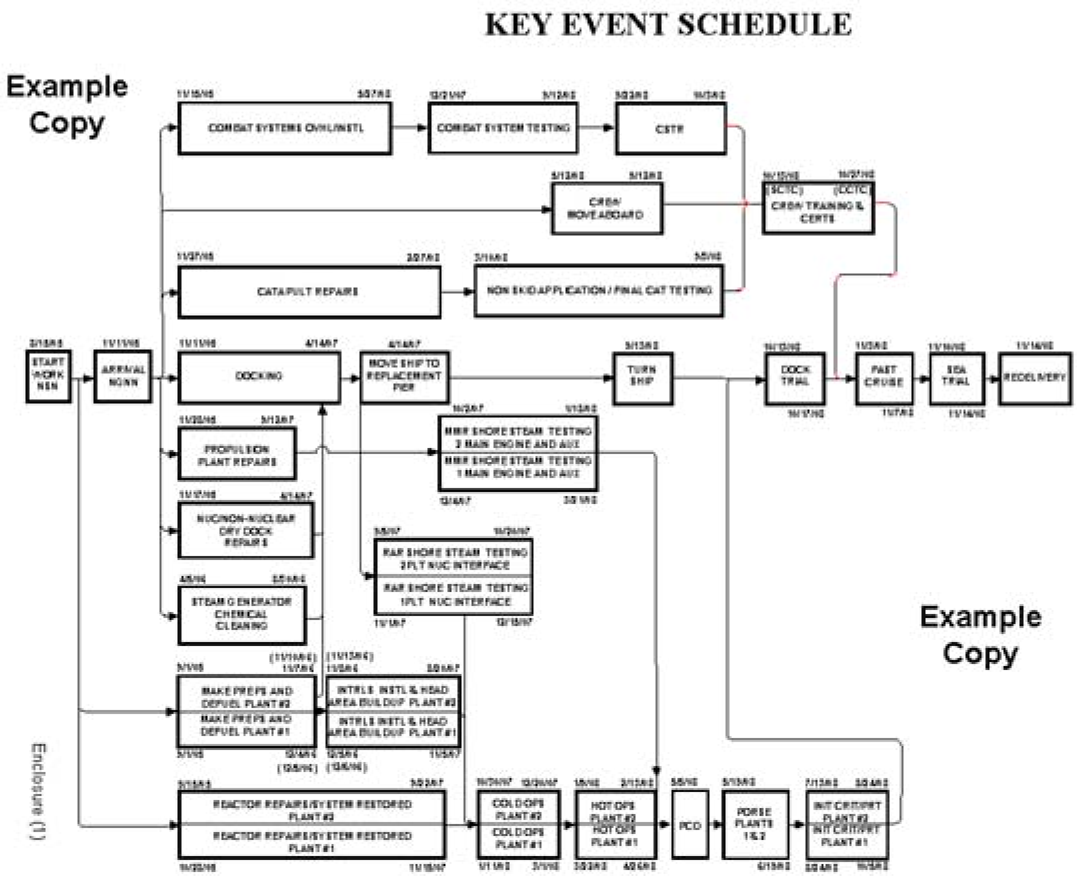

Figure 26. Example RCOH Key Event Schedule (From: [33])

By reducing and redistributing the amount of non-nuclear work (i.e., habitability, combats systems, and deck machinery) that can be conducted during a Depot Level Maintenance Availability (within a continuous maintenance cycle), the Navy can generate some cost savings.

Eliminating or de-scoping specific types of work is common to RCOHs. It is usually initiated by Congress to help fund other equally or more important programs. When Congress removes money out of the RCOH work package, it is the project team's responsibility to cancel work that will least affect the ship's mission readiness. One of areas of maintenance often chosen to remove is habitability work. Habitability work includes, but is not limited to, tiling, lagging, refurbishments, alterations, and installations and general beautification of the ship. It is often chosen as first to remove because, according to the SUPSHIPNN RCOH Project Supervisor and Planning Manager, it is less complicated to plan, SF can conduct a majority of the repairs, and it is less complicated to re-integrate in the package once money is regained. Another area prime for cancellation is the combat systems work. Combat systems work includes all infrastructure, distributive systems, alterations, installations, upgrades, and repairs associated with the ship's command, control, communications, computers, and intelligence (C4I) system. It is generally less expensive, conducted toward the end of the overhaul, and can be done relatively quickly. Since no work is usually removed from the nuclear package, this research suggests removing a reasonable amount of non-nuclear repairs from the AWP. The non-nuclear work can be a driver for cost overruns during refueling. In *Refueling and Complex Overhaul of the USS Nimitz (CVN 68), Lessons for the Future*, the authors determined that the nuclear portion of the CVN 68 RCOH had been accomplished within, or even below, the original contract cost leaving the non-nuclear portion accountable for the significant cost growth experienced. Reducing the nonessential, (work that can be conducted pier side during a regular maintenance cycle) non-nuclear work also has other benefits.

If much of the non-nuclear work capable of being accomplished outside of an RCOH was removed from the AWP, it would promote open competition between competing shipyards (Norfolk Naval Shipyard, Portsmouth Naval Shipyard, and NGC), which would enable the Navy to receive the best price for the desired work. As it stands, the Navy has little leverage with NGC over cost or schedule control since they are the sole source provider for carrier RCOHs. Reducing the non-nuclear work equates to reducing the amount of person-hours within an RCOH contract, which ultimately reduces

its total cost; however, this does not necessarily reduce its duration. The duration can be reduced by shortening the critical path work. The critical path work can be shortened by utilizing the cost savings from the reduced non-nuclear work to solely expedite the nuclear package through fast tracking or crashing the schedule. Fast tracking involves completing critical path activities in parallel that were originally planned in series. It often results in rework, usually increases risk, and requires more attention to communication [34]. Crashing is making cost and schedule tradeoffs to determine how to obtain the greatest amount of schedule compression for the least incremental cost while maintaining project scope; it usually results in increased costs [34]. Fast tracking or/and crashing the RCOH schedule are two viable options for schedule compression assuming that the resources (i.e., trade skills, specialized equipment, and labor) to do so are available.

D. STRATEGY THREE – AVOIDING THE RISK

The third strategy is to avoid the risk of excessive cost growth and schedule delay by increasing the power efficiency of carriers with the goal of eliminating the need for refuelings. It relies on modern technological advances in power distribution, efficiency, and quality to extend the service life of the reactor. Nuclear and conventional propulsion systems for Navy ships and submarines have both been improved in recent years. For example, nuclear power plants are now simpler in design, smaller, require less maintenance and personnel, and have an extended lifecycle. These reported improvements have eliminated the need for refueling newer submarines, such as the Virginia-class submarines whose reactor service life is now 33-years. Also, the first aircraft carrier to be built under the CVN 21 program, the USS Gerald R. Ford (CVN 78), will have a newly designed nuclear power plant. Delivery of CVN 78 is expected in fiscal year 2015 [35, p. 6].

Since 1977, the Navy has had a program to improve platform fuel efficiency. It has focused primarily on legacy systems and estimates that it has reduced the fuel consumption of the aircraft fleet by 6 percent [36, p. 50]. Furthermore, the Navy spent over $212 million from fiscal years 2003 through 2005, and plans to invest an additional

$264 million from fiscal years 2006 through 2011 to develop propulsion and ship support technologies designed to make future ships more fuel efficient and mission effective. These technologies are at various levels of maturity and are not yet ready for implementation. There is a focus on making electric motors smaller but more powerful, using high-speed generators without reduction gears, and using fuel cells. These motors still require fossil fuel as an energy source, but have the potential to reduce the amount needed and to improve ship operations [35, p. 3].

> According to Office of Naval Research officials, improvements to electrical components will generally improve fuel efficiency and overall mission effectiveness of future Navy surface ships. For example, superconducting motors, using special wiring to lower the resistance of electricity flow and employing cryogenics to reduce temperatures within the motor, will be more powerful and smaller, thereby reducing weight and saving onboard space for other purposes. High-speed generators, also projected to be smaller, will make it possible to couple high-speed gas turbine engines directly to the generators without the use of reduction gears, thereby reducing weight, saving space, and making the engines more fuel-efficient. Conversely, the fuel cell technology the Office of Naval Research is pursuing involves extracting hydrogen from diesel fuel, which can be safely stored and transferred at sea, according to the official. The hydrogen is used to produce electrical power without the use of diesel or gas turbine engines. The use of fuel cells would also permit a ship's power system to be dispersed throughout the ship, increasing the ship's ability to survive if attacked, according to Navy officials. These systems target a 30- to 50-percent improvement in fuel efficiency and reduced maintenance compared to current power plants. The more advanced molten carbonate and solid oxide systems provide higher efficiencies, especially if the high quality waste heat is captured. The Navy's challenge is to develop high energy density, marine environment compatible systems, and compact, efficient, and reliable fuel reforming systems capable of handling marine diesel fuels [36, p. 57].

The Office of Naval Research officials stated that fuel cell technology is promising for future naval application and has already completed some prototype testing; however, that the technology is at least 3- to 5-years away from acquisition consideration [35, p. 7].

The Navy has a range of technologies that improve the efficiency of its ships. The utilization of these technologies and products has been primarily through no- and low-cost routes, such as the normal overhaul process or procedural changes. Some of technologies for achieving energy efficiency in Navy platforms are in fleet diesel power plants, hull coating and cleaning, auxiliary systems, sensors, controls and procedures, and hotel loads (i.e., functions such as lighting and fresh water production) [36, pp. 52, 53].

Dr. Amory Lovins, the director of the Rocky Mountain Institute (RMI) and a member of the Defense Science Board (DSB) task force, estimated that up to 30% of the Navy's non-aviation fuel appeared to be used to generate power for hotel loads. In 2001, the RMI conducted a study for the Navy on the energy use of the USS Princeton (CG-59). It found that hotel loads on these ships could be substantially reduced. According to the DSB report, the study found retrofittable hotel-load electric savings potential on the order of 20 to 50 percent. Many of the savings opportunities were purely operational, requiring little or no investment. In an online article about the RMI study, Dr. Lovins stated:

> The Naval Sea Systems Command's [NAVSEA's] able engineers had estimated that 19 percent could be saved on ships of this class, of which Princeton was in the top one fourth for efficiency. Our preliminary survey found gratifyingly large potential savings: perhaps, if found feasible, as much as several times NAVSEA's expectations. The RMI team found that retrofitting motors, pumps, fans, chillers, lights, and potable water systems could save an estimated 20-50 percent of the ship's electricity. That could cut total fuel use by an estimated 10-25 percent.
>
> Just as in civilian facilities ashore, the RMI team started by calculating what it's worth to save a kilowatt-hour. Since the electricity is being made inefficiently from fuel that's mainly delivered by “oiler” ships, the answer is 27 cents, six times a typical industrial tariff ashore. This high cost makes “megawatts” a prime target for significant reductions. For example, each percentage point of improved efficiency in a single 100-horsepower always-on motor is worth $1,000 a year. Each chiller could be improved to save its own capital cost's worth of electricity (about $120,000) every eight months. About $400,000 a year could be saved if -- under noncritical, low-threat conditions -- certain backup systems were set to come on automatically when needed rather than running all the time. Half that saving could come just from two 125-horsepower firepumps that currently pump seawater continuously aboard, around the ship, and back

> overboard. Princeton's total electricity-saving potential could probably cut her energy costs by nearly $1 million a year, or about $10 million in present value [over the ship's lifecycle], while improving her warfighting capability [37].

E. ANALYSIS OF ALTERNATIVES (AOA)

As described in Sections B through D, the three mitigation strategies proposed for increasing cost and time effectiveness during an RCOH are (1) assume the risk by maintaining the current process, (2) control the risk through reduced work and schedule compression and (3) avoid the risk by increasing the energy efficiency of a carrier to ultimately eliminate the need for nuclear refueling. Chapter I defined C_{eff} as any modification(s) in planning, scheduling, and/or conducting an RCOH that resulted I the following.

- less cost for the more performance (work accomplished) than the previous RCOH
- less cost for the same amount of performance of the previous RCOH
- less cost for less performance than previous RCOH
- same cost for more performance than previous RCOH

TE was defined as any modification(s) in planning, scheduling and/or conducting an RCOH that resulted in a schedule duration of less than or equal to 33 months. It was also broadly defined as the following.

- less time for the more performance (work accomplished)
- less time for the same amount of performance
- less time for less performance than previous
- same time for more performance

The following is a qualitative analysis of strategies one through three based on the data found within the context of this thesis.

1 – Strategy One: Maintain Current Process

Pros

- There is a since of process familiarity since almost three RCOHs have been completed.
- There is less planning and execution uncertainty due to process familiarity.

- Each RCOH incorporates the lessons learned from previous overhauls.
- There is some level of learning experienced (learning curve).

Cons

- It is difficult to forecast program success.
- It is difficult to quantify learning.
- The current process does not take into consideration a severely constrained budget.
- There is an issue of economic vulnerability to sole source contractor.

2 – Strategy Two: Reduce Work and Schedule Compression

Pros

- There is an overall schedule duration reduction.
- There is a less complicated planning process.
- There are less planning costs.
- There is less integration required.

Cons

- There is the potential for reduced modernization and combat superiority.
- There is the potential for increased program risk.
- There is the potential for increased cost risk.

3 – Strategy Three: Increase Power Efficiency/Eliminate RCOH

Pros

- There is minimal cost or schedule impact.
- There is the potential for increased power efficiency.
- There is the potential for increased operational availability.

Cons

- There are increased costs throughout the maintenance lifecycle.
- There are potentially longer planned incremental availabilities (PIA)s.
- The power efficiency technologies are currently immature.
- Advances in reactor technology apply only to future carriers.

Figure 27 graphically compares the results of the individual analyses. The red squares represent undesirable outcomes with greater cost and time being the least desirable outcome. The green squares present desirable outcomes with less cost and time being the most desirable outcome. The blue squares represent acceptable outcomes based on the priorities of the program office. The numbers 1, 2, and 3 represent each mitigation strategy, respectively. The following analysis was conducted through expert opinion and interviews with key RCOH maintenance personnel. The data was analyzed using $1.9 billion and 33 months as the baseline cost and schedule duration (see Chapter I). The top horizontal row in the matrix represents the possibility of an RCOH costing more, the same, or less than $ 1.9 billion while the far left column represents an RCOH taking more, the same, or less time than 33 months.

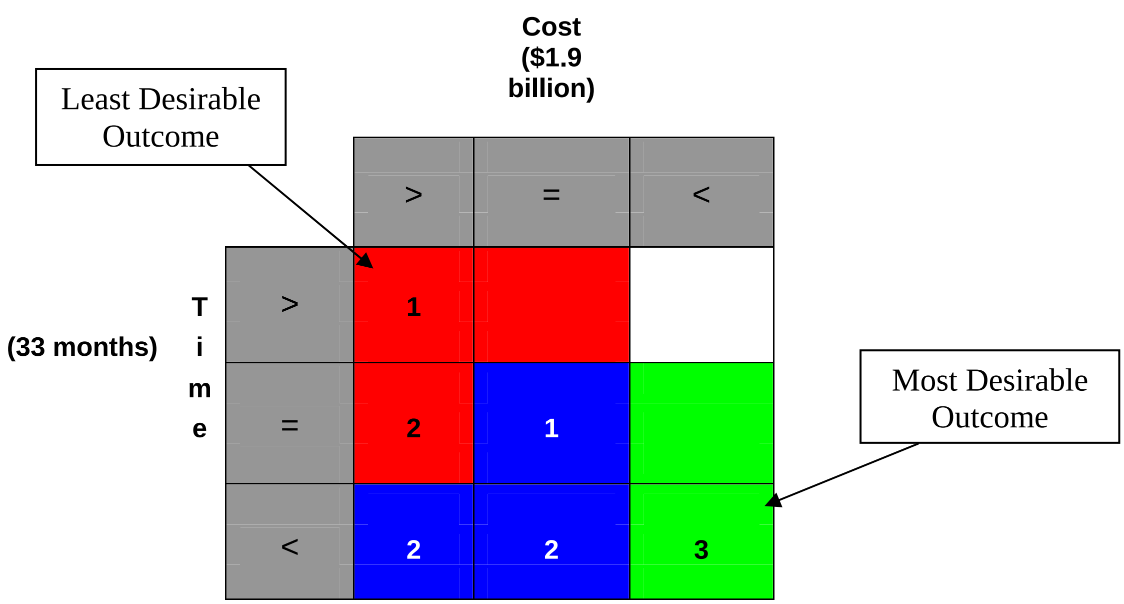

Figure 27. Cost, Time, and Solution Matrix.

The matrix shows that within the context of this thesis, the least desirable outcome is strategy one (1) while the optimal solution to increase cost and time effectiveness of an RCOH is strategy three (3).

F. CHAPTER SUMMARY

This chapter assessed the three mitigation strategies derived at the end of Chapter IV. It discussed how an RCOH is planned and executed and the implications associated with maintaining the current process. It also discussed the impacts of reducing the scope of work in the availability work package (AWP) while compressing the overall schedule. It then discussed advancements in reactor technologies and the possibility for more power efficient carriers with the goal of eliminating the need for refueling. An AoA was provided to illustrate graphically the differences in the strategies and an optimal solution (strategy three) was determined. This next chapter is the recommendation based on the scope of this research followed by the conclusion.

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VI. CONCLUSIONS AND FUTURE WORK

A. INTRODUCTION

This chapter presents the conclusions, recommendations, and future work generated from completing this thesis. Section B discusses how this thesis addressed the research question presented in Chapter I. Section C discusses general findings and conclusions regarding the premise of this thesis. Section D summarizes the recommendation generated as a result of completing the research and analysis for this thesis. Section E summarizes potential areas for future work identified during the course of the thesis. Section F summarizes the chapter.

B. DISCUSSION OF RESEARCH QUESTION

The research question described in Chapter I was developed to provide a focal area for the thesis and shape the research's subsequent analysis of the data collected. The author found that the research and analysis conducted over the course of this thesis met the objectives set forth in the original research question. The methodology presented in Chapter I, Section F was used successfully to address the research question: By reducing risk, how can the Navy decrease the time in lay-up and increase the cost effectiveness *of* a Nimitz-class aircraft carrier in dry dock during the execution phase of an RCOH?

This research question set an objective to investigate the process in which the Navy plans, schedules, and conducts RCOHs to access the likelihood of reducing a carriers execution cost and time in layup.

The information provided in Chapter II discussed the concept of risk, its management, key activities, and application as a systematic approach to the expeditious and thorough evaluation of complex systems or systems of systems under various operational and extreme conditions.

Chapter III described the stakeholders in an RCOH and defined their impact or ability to be impacted by the overhaul. The functional decomposition partitions conducting an RCOH into six primary functions: (1) to plan, (2) to communicate, (3) to

budget, (4) to fund, (5) to execute, and (6) to manage. These six primary functions were further analyzed to provide a broad overview of what an RCOH required in terms of labor hours, resources, and planning. From the “to plan” function, seven major industrial components were determined that characterized the planning phase of the overhaul. It revealed that these major industrial complexes determined the type and scope of work accomplished during the overhaul. A process flow diagram was then presented that illustrated the sequence of events necessary to coordinate and institute an RCOH effort starting with congressional authorization to the aircraft carrier’s redelivery to the Navy.

Chapter IV used the six main objectives to perform an RCOH found in Chapter III to identify risks associated with conducting an overhaul within the context of increasing cost and time effectiveness. The risks were evaluated and assessments of likelihood, consequences, and impact to the cost, schedule, and performance (see Section D of Chapter II) were made. From this assessment, the risks were divided into low, moderate, and high levels. Using the software application Probability/Consequences and Scheduling, a matrix was constructed to determine the major risks that could adversely affect an RCOH. From this matrix, ten risks were determined that could jeopardize the successful administration and completion of an overhaul. Of the ten risks discovered, two were selected for further in-depth analysis. From these two risks, three mitigations strategies were introduced and analyzed.

Chapter V assessed the three mitigation strategies derived at the end of Chapter IV. Strategy 1 focused on RCOH planning and execution, along with the implications associated with maintaining the current process. Strategy 2 discussed the impacts of reducing the scope of work in the availability work package (AWP) while compressing the overall schedule. Strategy 3 discussed advancements in reactor technology and the possibility of more power efficient carriers with the goal of eliminating the need for refueling. An analysis of alternates graphically illustrated the differences in the strategies and the best solution of the three (strategy 3) was determined as the most time and cost effective solution.

C. CONCLUSION REGARDING THE THESIS PREMISE

The premise of this thesis was that by utilizing risk management within the systems engineering process, solutions for confronting the growing costs and durations of RCOHs were possible. To evaluate this premise, one needs full access to cost data records, work breakdown structures, and integrated master schedules from the previous RCOHs. Although this study did not include this type of quantitative data, the research found much evidence to support this premise throughout policies, guides, and processes. The following paragraphs summarize the conclusions founded on evidence presented throughout the thesis.

1. Each RCOH is Unique

As discussed in Chapter I, each RCOH has been longer than the prescribed 33-month duration and the costs have steadily increased over time. Although each carrier's maintenance is planned using historical, parametric, and empirical data, each aircraft carrier's material condition and program office's priority is unique which makes the maintenance requirements (non-nuclear and nuclear work packages) unique. Due to the randomness in the ship's material condition, the government's desired level of modernization, and the prime contractors increasing service costs (mentioned in Chapter V), a precise duration as well as cost for an RCOH is difficult to forecast accurately based on only three such attempts.

2. An RCOH Schedule is Dependent upon the Work in the Nuclear Package

As discussed in Chapter V, the nuclear work package or CARPOP is the critical path of an RCOH. To compress a RCOH schedule, the nuclear work package would need to be fast tracked, crashed, or reduced. As stated previously in Chapter V, fast tracking involves completing critical path activities in parallel originally planned in the series. Crashing is making cost and schedule tradeoffs to determine how to obtain the greatest amount of schedule compression for the least incremental cost while maintaining project scope. These strategies may increase technical performance risk. An increase in technical performance risk may result in an increase in maintenance errors, which may lead to an

increase in equipment errors, which may exacerbate safety hazards, which may result in loss of life. Additionally, according to a SUPSHIP NN Contract Specialist, the increase in risk would be accompanied by an increase in service, overhead, and labor (overtime) costs. Therefore, as illustrated in Figure 27, fast tracking results in an effectiveness profile that poses greater cost for equal performance. Further studies on the relationship between schedule compression, cost, and the risks associated with nuclear propulsion work during an RCOH are warranted and beyond the scope of this research. However, with that said, it is the author's unsubstantiated opinion that the increase in performance risk as well as the potential overall increase in cost was undesirable compared to the schedule compression.

3. Time and Cost Effectiveness Are Not Possible without Loss

As discussed above, decreasing the schedule duration by fast tracking or crashing resulted in greater performance risk to the nuclear propulsion work package. Performance risk was defined by this thesis as the probability of correctly accomplishing a task within a specific set of parameters, constraints, and time. If not properly mitigated, a nuclear propulsion performance risk may ultimately result in a loss of mission readiness, operational availability, or life.

To cut costs, this research suggested limiting the amount of non-nuclear work accomplished during an RCOH, which in turn, limits the amount of modernization anticipated by the Navy once the carrier is redelivered to the fleet. This would be deemed a performance loss to the Navy because (1) much non-nuclear work historically accomplished would be delayed, and (2) the ship would return to the fleet without any enhancements thereby threatening its technical superiority ("tip of the spear" philosophy). The deferred modernization work package would be accomplished during the regular carrier maintenance cycle and may have a greater impact on its maintenance intervals.

Finally, an RCOH is scheduled for a specific amount of time and cost. However, during an overhaul, hundreds of inspection reports, additional mandated technical requirements, and engineering change proposals are issued. Hypothetically, if the

program office refused to integrate any of the requested changes into the AWP in an effort to stay on cost and schedule, then the risk associated with not having that specific work accomplished would be transferred to the customer (ship's force). However, the risk would result in some type of loss experienced by an operator. Therefore, it would be deemed an operation loss.

4. Greater Gains in Energy Efficiency May Be Possible with Low to No Cost from the Government

As discussed in Chapter V, Dr. Amory Lovins estimates that as much as 30% of the Navy's non-aviation fuel appeared to be used to generate power for hotel loads. A study of the USS Princeton found retrofittable hotel-load electric savings potential on the order of 20 to 50 percent, with significant future opportunities to assess. Many of the savings opportunities were purely operational, requiring little or no investment. Although some of Dr. Lovins results are questionable, further studies on the relationship between hotel services, power efficiency, and carrier operations are warranted beyond the scope of this research. By conducting future studies on carrier platforms coupled with the continual advancements in reactor technology mentioned in Section D of Chapter V, the Navy may be able to experience the same or greater results than those suggested by the CG-59.

D. SUMMARY OF RECOMMENDATIONS

The following recommendations are made for further accomplishment of RCOHs in general. Successful implementation of the recommendations summarized below will help stem the growing costs and durations associated with carrier overhauls.

1. To Do or Not To Do

From the data gathered during the course of writing this research, the author believes that the most cost and time effective method for addressing the challenge of increasing costs and durations of RCOHs is not to conduct them at all. The comparative data analysis from Section E of Chapter V supports the same conclusion revealing that improving power efficiency and thereby extending the service of the nuclear reactor and

eliminating the need for refueling (strategy 3) was the best of the three solutions. As discussed in Section D of Chapter V, the innovations and advancements in nuclear reactors currently only apply to submarines with the first aircraft carrier application in 2015. Furthermore, the lifecycle of an aircraft carrier is 50 years whereas the extended life service of the new reactors is 33 years. Additionally, to increase power efficiency on aircraft carriers, a complete case study would need to be conducted to determine what equipment could be replaced, upgraded, or retrofitted as well as what technical specifications and logistic support would need to be eliminated, revamped, or updated.

Similarly, the option to maintain the current process is not viable since the economic stability of the government is in recovery and is strained by national commitments [38]. Through the evaluation of the data contained within this research, it is the author's sole opinion that maintaining the current RCOH process is not an aggressive strategic countermeasure for combating rising costs and extended schedule durations.

a. Cost Effectiveness

With respect to increasing the cost effectiveness of an RCOH, this research recommends limiting the amount of non-nuclear work in the AWP and deferring that work to either a selective restrictive availability (SRA) or a regularly schedule maintenance interval (i.e., PIA or DPIA). As stated in Section E Chapter V, a reduction in cost will be experienced due to the reduced amount of person-hours, planning, scheduling and integration associated with NGC's designation as the LMA. This research does not provide specific work to remove nor was it within its scope to do so; however, it does suggest some areas of strong scrutiny such as habitability, and combat systems maintenance. The rationale for this suggestion is based on the idea of open competition. With the Navy's designation of NGC as the sole provider for carrier overhauls, it (the Navy) has very little leverage or control over cost during contract negotiations (often awarded a cost plus incentive fee contracted supplemented by levels of efforts) and execution. If a majority of the non-nuclear repair work could be offered to more shipyards for accomplishment, the government would receive competitive prices for the

work to be accomplished. This would give the government more flexibility in the decision making process and would encourage NGC to compete with its peers for continued government funding.

b. *Time Effectiveness*

As discussed in Chapter V, the critical path of an RCOH is the nuclear propulsion work package. If schedule duration is the priority of the program office, then with respect to time effectiveness, it is the author's recommendation that NAVSEA 08 scrutinizes the types of work in the CARPOP and determines what work can be accelerated or compressed. This inherently increases the risk and cost to the program but if planned in advanced, many of the concerns may be mitigated.

c. *Time and Cost Effectiveness*

To achieve both time and cost effectiveness simultaneously, the author recommends no longer conducting RCOHs because, within the scope of thesis, they are inherently cost and time ineffective.

From a time effective perspective, there is not a large enough sample size (three RCOHs) to conclusively support any single point of view statistically but according to the data collected from the previous RCOHs, it can be inferred that the 33-month schedule duration may not be enough time to complete an overhaul successfully (see Chapter I). Further studies on the relationship between a variety of schedule durations (i.e., 36-, 40-, and 42-months), cost, and operational availability are warranted and beyond the scope of this research. However, it is the author's opinion that RCOHs planned and conducted under the premise of completing within a 33-month window are inherently time ineffective.

From a cost effectiveness perspective, the final cost of an RCOH to the government is 70% of what it costs to build a new aircraft carrier. Listed below (Figure 28) are the final RCOH costs (in constant dollars) from the previous overhauls. Estimates

for the planning costs were obtained via a telephone interview with Mr. Mark Bowman, the Waterfront Operations Department's Business Operations Manager (Code 150A3) at SUPSHIP NN.

CVN	Planning Cost	Execution Cost	Post Selective Availability Cost	Total
68	500,000,000	1,200,000,000	1,950,000,000	3,150,000,000
69	400,000,000	1,360,000,000	1,820,000,000	3,180,000,000
70	500,000,000	1,940,000,000	1,180,000,000	3,120,000,000

Projected Cost

Figure 28. RCOH Planning, Execution, and Post Selective Availability Costs.

The government spends approximately $4.059 billion to build a new Nimitz-class aircraft carrier (Figure 29). Since the average cost of a RCOH is $3.15 billion, the government spends approximately 77.6% of what it costs to build a new aircraft carrier to conduct a RCOH.

$$\frac{3.15}{4.45} = 0.776 \text{ or } 77.6\%$$

$$\frac{3.18}{4.45} = 0.783 \text{ or } 78.3\%$$

$$\frac{3.12}{4.45} = 0.768 \text{ or } 76.8\%$$

From a consumer's point of view, this is a highly unfavorable transaction. For example, if an automobile is purchased for $20,000 and will last for 200,000 miles, few consumers would pay up to 30% of the vehicles purchase price for a 100,000-mile service check. However, almost no consumer would be willing to pay $14,000 (70%) for a mid-life maintenance service without strongly considering replacing the automobile. Applying the same logic to aircraft carriers, the following calculations were conducted.

The total cost of ownership or lifecycle cost of a nuclear-powered aircraft carrier compared to a conventional carrier is shown below.

Table 2: Life-Cycle Costs for a Conventionally Powered Carrier and a Nuclear-Powered Carrier (based on a 50-year service life)

Fiscal year 1997 dollars in billions

Cost category	Conventionally powered carrier	Nuclear-powered carrier
Investment cost[a]	**$2.916**	**$6.441**
Ship acquisition cost	2.050	4.059
Midlife modernization cost	0.866	2.382
Operating and support cost	**11.125**	**14.882**
Direct operating and support cost	10.436	11.677
Indirect operating and support cost	**0.688**	**3.205**
Inactivation/disposal cost	**0.053**	**0.899**
Inactivation/disposal cost	0.053	0.887
Spent nuclear fuel storage cost	n/a	0.013
Total life-cycle cost	**$14.094**	**$22.222**

Note: Numbers may not add due to rounding.

[a]CVN investment cost includes all nuclear fuel cost; CV fuel is included in operations and support activities.

Source: GAO's analysis.

Figure 29. The total cost of ownership or lifecycle cost of a nuclear-powered aircraft carrier compared to a conventional carrier (From: [39])

Using the data from Figure 29, the Navy pays $22.22 billion for a 50-year service life of a nuclear powered aircraft carrier. This means it spends $444 million/1 year to maintain this capability.

$$\frac{\$22.22\ billion}{50\ years} = \frac{\$0.444\ billion}{1\ year}\ or\ \frac{\$444\ million}{1\ year}$$

Table 3 shows a model of the 50-year lifecycle cost of an aircraft carrier adjusted for inflation at an average annual rate of 2.71% [40] over 100-years. The bold numbers reflect the initial costs used to configure the model. They are also the numbers used to determine the cumulative and non-cumulative annual costs. For example, in year two, the cumulative cost is the summation of the ship acquisition cost over seven years and the cumulative cost after the first year (0.58 + 0.58 = 1.16). The green highlighted rows represent the beginnings of carrier construction (for simplicity, it was modeled as a 7-year evenly divided process including commissioning), the blue rows represent RCOHs (for simplicity, it was modeled as a 3-year evenly divided process) and the red rows represent the end of carrier lifecycles (includes inactivation, disposal, and spent nuclear

fuel costs). The model demonstrates that the longer the interval between carrier constructions, the greater the acquisition and lifecycle costs due to inflation. For example, the cost to build a carrier in 26 years is $7.92 billion whereas building one in 43 years costs $12.48 billion.

	Cost Over 50-Years	Cost/Year	
4.059	Ship Acquisition cost	One time cost	
2.382	Midlife modernization cost	One time cost	
11.677	Direct operating cost	**0.23354**	= 11.67/50
3.205	indirect operating cost	**0.0641**	= 3.205/50
0.887	Inactivation/disposal cost	One time cost	
0.013	spent nuclear fuel storage cost	One time cost	
22.223	TOTAL Lifecycle Cost		

Inflation
2.71%

Years	Ship Acquisition Cost	Ship Acquisition Cost Over 7-Years	Direct Operating Cost	Indirect Operating Cost	Inactivation / Disposal Cost	Spent Nuclear Fuel Storage Cost	RCOH Cost	RCOH Cost Over 3-Years	Cost/Year Non-Cumulative	Cumulative Cost/Year
1	**4.06**	**0.58**	0.2335	0.0641	0.89	0.01	2.38		4.06	**0.58**
2	4.17	**0.58**	0.2399	0.0658	0.91	0.01	2.45		0.00	**1.16**
3	4.28	**0.58**	0.2464	0.0676	0.94	0.01	2.51		0.00	**1.74**
4	4.40	**0.58**	0.2530	0.0695	0.96	0.01	2.58		0.00	**2.32**
5	4.52	**0.58**	0.2599	0.0713	0.99	0.01	2.65		0.00	**2.90**
6	4.64	**0.58**	0.2669	0.0733	1.01	0.01	2.72		0.00	**3.48**
7	4.77	**0.58**	0.2742	0.0753	1.04	0.02	2.80		0.35	**4.06**
8	4.90		**0.2816 0.**	**0773**	1.07	0.02	2.87		0.36	**4.42**
9	5.03		**0.2892 0.**	**0794**	1.10	0.02	2.95		0.37	**4.79**
10	5.16		**0.2971 0.**	**0815**	1.13	0.02	3.03		0.38	**5.17**
11	5.30		**0.3051 0.**	**0838**	1.16	0.02	3.11		0.39	**5.56**
12	5.45		**0.3134 0.**	**0860**	1.19	0.02	3.20		0.40	**5.95**
13	5.60		**0.3219 0.**	**0884**	1.22	0.02	3.28		0.41	**6.36**
14	5.75		**0.3306 0.**	**0907**	1.26	0.02	3.37		0.42	**6.79**
15	5.90		**0.3396 0.**	**0932**	1.29	0.02	3.46		0.43	**7.22**
16	6.06		**0.3488 0.**	**0957**	1.32	0.02	3.56		0.44	**7.66**
17	6.23		**0.3582 0.**	**0983**	1.36	0.02	3.65		0.46	**8.12**
18	6.40		**0.3679 0.**	**1010**	1.40	0.02	3.75		0.47	**8.59**
19	6.57		**0.3779 0.**	**1037**	1.44	0.02	3.85		0.48	**9.07**
20	6.75		**0.3882 0.**	**1065**	1.47	0.02	3.96		0.49	**9.57**

21	6.93		**0.3987 0.**	**1094**	1.51	0.02	4.07		0.51	**10.07**
22	7.12		**0.4095 0.**	**1124**	1.56	0.02	4.18		0.52	**10.60**
23	7.31		**0.4206 0.**	**1154**	1.60	0.02	4.29		0.54	**11.13**
24	7.51		**0.4320 0.**	**1186**	1.64	0.02	4.41		0.55	**11.68**
25	7.71		**0.4437**	**0.1218**	1.69	0.02	**4.53**	**1.51**	5.09	**13.76**
26	7.92		**0.4557 0.**	**1251**	1.73	0.03	4.65	**1.51**	0.58	**15.84**
27	8.14		**0.4680 0.**	**1285**	1.78	0.03	4.77	**1.51**	0.60	**17.95**
28	8.36		**0.4807 0.**	**1319**	1.83	0.03	4.90		0.61	**18.56**
29	8.58		**0.4938 0.**	**1355**	1.88	0.03	5.04		0.63	**19.19**
30	8.82		**0.5071 0.**	**1392**	1.93	0.03	5.17		0.65	**19.84**
31	9.06		**0.5209 0.**	**1430**	1.98	0.03	5.31		0.66	**20.50**
32	9.30		**0.5350 0.**	**1468**	2.03	0.03	5.46		0.68	**21.18**
33	9.55		**0.5495 0.**	**1508**	2.09	0.03	5.60		0.70	**21.88**
34	9.81		**0.5644 0.**	**1549**	2.14	0.03	5.76		0.72	**22.60**
35	10.08		**0.5797 0.**	**1591**	2.20	0.03	5.91		0.74	**23.34**
36	10.35		**0.5954 0.**	**1634**	2.26	0.03	6.07		0.76	**24.10**
37	10.63		**0.6115 0.**	**1678**	2.32	0.03	6.24		0.78	**24.88**
38	10.92		**0.6281 0.**	**1724**	2.39	0.03	6.41		0.80	**25.68**
39	11.22		**0.6451 0.**	**1771**	2.45	0.04	6.58		0.82	**26.50**
40	11.52		**0.6626 0.**	**1819**	2.52	0.04	6.76		0.84	**27.35**
41	11.83		**0.6806 0.**	**1868**	2.58	0.04	6.94		0.87	**28.21**
42	12.15		**0.6990 0.**	**1919**	2.65	0.04	7.13		0.89	**29.11**
43	**12.48**	**1.78**	**0.7180**	**0.1971**	2.73	0.04	7.32		13.40	**31.80**
44	12.82	**1.78 0.**	**7374**	**0.2024**	2.80	0.04	7.52		0.94	**34.53**
45	13.17	**1.78 0.**	**7574**	**0.2079**	2.88	0.04	7.73		0.97	**37.27**
46	13.52	**1.78 0.**	**7779**	**0.2135**	2.95	0.04	7.93		0.99	**40.05**
47	13.89	**1.78 0.**	**7990**	**0.2193**	3.03	0.04	8.15		1.02	**42.85**
48	14.27	**1.78 0.**	**8207**	**0.2252**	3.12	0.05	8.37		1.05	**45.68**
49	14.65	**1.78 0.**	**8429**	**0.2313**	3.20	0.05	8.60		1.07	**48.54**
50	15.05		**0.8657**	**0.2376**	**3.29**	**0.05**	8.83		4.44	**52.98**
51	15.46		**0.8892 0.**	**2441**	3.38	0.05	9.07		1.13	**54.11**
52	15.88		**0.9133 0.**	**2507**	3.47	0.05	9.32		1.16	**55.27**
53	16.31		**0.9380 0.**	**2575**	3.56	0.05	9.57		1.20	**56.47**
54	16.75		**0.9635 0.**	**2644**	3.66	0.05	9.83		1.23	**57.70**
55	17.20		**0.9896 0.**	**2716**	3.76	0.06	10.09		1.26	**58.96**
56	17.67		**1.0164 0.**	**2790**	3.86	0.06	10.37		1.30	**60.25**
57	18.15		**1.0439 0.**	**2865**	3.96	0.06	10.65		1.33	**61.58**
58	18.64		**1.0722 0.**	**2943**	4.07	0.06	10.94		1.37	**62.95**
59	19.15		**1.1013 0.**	**3023**	4.18	0.06	11.23		1.40	**64.35**
60	19.66		**1.1311 0.**	**3105**	4.30	0.06	11.54		1.44	**65.80**
61	20.20		**1.1618 0.**	**3189**	4.41	0.06	11.85		1.48	**67.28**
62	20.74		**1.1933 0.**	**3275**	4.53	0.07	12.17		1.52	**68.80**
63	21.31		**1.2256 0.**	**3364**	4.65	0.07	12.50		1.56	**70.36**
64	21.88		**1.2588 0.**	**3455**	4.78	0.07	12.84		1.60	**71.96**
65	22.48		**1.2929 0.**	**3549**	4.91	0.07	13.19		1.65	**73.61**
66	23.09		**1.3280 0.**	**3645**	5.04	0.07	13.54		1.69	**75.30**
67	23.71		**1.3640 0.**	**3744**	5.18	0.08	13.91		1.74	**77.04**
68	24.35		**1.4009 0.**	**3845**	5.32	0.08	14.29		1.79	**78.83**
69	25.01		**1.4389 0.**	**3949**	5.46	0.08	14.68		1.83	**80.66**

70	25.69		**1.4779 0.**	**4056**	5.61	0.08	15.07		1.88	**82.55**
71	26.39		**1.5179 0.**	**4166**	5.77	0.08	15.48		1.93	**84.48**
72	27.10		**1.5591 0.**	**4279**	5.92	0.09	15.90		1.99	**86.47**
73	27.84		**1.6013 0.**	**4395**	6.08	0.09	16.33		2.04	**88.51**
74	28.59		**1.6447 0.**	**4514**	6.25	0.09	16.78		2.10	**90.60**
75	29.37		**1.6893**	**0.4637**	6.42	0.09	**17.23**	**5.74**	19.38	**98.50**
76	30.16		**1.7351 0.**	**4762**	6.59	0.10	17.70	**5.74**	2.21	**106.45**
77	30.98		**1.7821 0.**	**4891**	6.77	0.10	18.18	**5.74**	2.27	**114.47**
78	31.82		**1.8304 0.**	**5024**	6.95	0.10	18.67		2.33	**116.80**
79	32.68		**1.8800 0.**	**5160**	7.14	0.10	19.17		2.40	**119.20**
80	33.57		**1.9309 0.**	**5300**	7.33	0.11	19.69		2.46	**121.66**
81	34.48		**1.9833 0.**	**5443**	7.53	0.11	20.23		2.53	**124.19**
82	35.41		**2.0370 0.**	**5591**	7.74	0.11	20.78		2.60	**126.78**
83	36.37		**2.0922 0.**	**5743**	7.95	0.12	21.34		2.67	**129.45**
84	37.36		**2.1489 0.**	**5898**	8.16	0.12	21.92		2.74	**132.19**
85	38.37		**2.2071 0.**	**6058**	8.38	0.12	22.51		2.81	**135.00**
86	39.41		**2.2670 0.**	**6222**	8.61	0.13	23.12		2.89	**137.89**
87	40.48		**2.3284 0.**	**6391**	8.84	0.13	23.75		2.97	**140.86**
88	41.58		**2.3915 0.**	**6564**	9.08	0.13	24.39		3.05	**143.91**
89	42.70		**2.4563 0.**	**6742**	9.33	0.14	25.05		3.13	**147.04**
90	43.86		**2.5229 0.**	**6925**	9.58	0.14	25.73		3.22	**150.25**
91	45.05		**2.5912 0.**	**7112**	9.84	0.14	26.43		3.30	**153.55**
92	46.27		**2.6615 0.**	**7305**	10.11	0.15	27.15		3.39	**156.95**
93	**47.52**	**6.79**	**2.7336**	**0.7503**	10.38	0.15	27.88		51.01	**167.22**
94	48.81	**6.79 2.**	**8077**	**0.7706**	10.66	0.16	28.64		3.58	**177.59**
95	50.13	**6.79 2.**	**8838**	**0.7915**	10.95	0.16	29.41		3.68	**188.05**
96	51.49	**6.79 2.**	**9619**	**0.8130**	11.25	0.16	30.21		3.77	**198.61**
97	52.89	**6.79 3.**	**0422**	**0.8350**	11.55	0.17	31.03		3.88	**209.28**
98	54.32	**6.79 3.**	**1246**	**0.8576**	11.87	0.17	31.87		3.98	**220.05**
99	55.79	**6.79 3.**	**2093**	**0.8809**	12.19	0.18	32.73		4.09	**230.93**
100	57.30		**3.2963**	**0.9047**	**12.52**	**0.18**	33.62		16.90	**247.83**

Table 3. 50-Year Lifecycle Cost Model

Color Legend

Bold Numbers – Base Numbers used for Calculations

Green Highlight- New Ship Construction

Blue Highlight- RCOH

Red Highlight – Ship Disposal

Alternatively, if the service life of a nuclear carrier was reduced to 33 years with the removal of an RCOH, the lifecycle cost of a carrier would be \$14.48 billion and the Navy would spend approximately \$438 million/year to maintain this capability. The 33-year lifecycle cost was derived from the following calculations using the data from Figure 29.

$$Ship\ Acquistion\ Cost = \$4.059\ billion$$

$$Direct\ Operating\ Cost = \left(\frac{\$11.677\ billion}{50\ years}\right) 33\ years = \$7.70682\ billion$$

$$Indirect\ Operating\ Cost = \left(\frac{\$3.205\ billion}{50\ years}\right) 33\ years = \$2.1153\ billion$$

$$Inactivation\ /\ Disposal\ Cost = \left(\frac{\$0.887\ billion}{50\ years}\right) 33\ years = \$0.58542\ billion$$

$$Spent\ Nuclear\ FuelStorage\ Cost = \left(\frac{\$0.013\ billion}{50\ years}\right) 33\ years = \$0.00858\ billion$$

$$Total\ Lifecylce\ Cost = \$4.059 + \$7.70682 + \$2.1153 + \$0.58542 + \$0.00858 = \$14.475\ billion$$

$$\frac{\$14.48\ billion}{33\ years} = \frac{0.438\ billion}{1\ year}\ or\ \frac{\$438\ million}{1\ year}$$

	Cost Over 33-Years	Cost/Year	
4.059	Ship Acquisition cost	One time cost	
0.000	Midlife modernization cost	0	
7.707	Direct operating cost	**0.23354**	= 7.707/33
2.115	indirect operating cost	**0.0641**	= 2.115/33
0.585	Inactivation/disposal cost	One time cost	
0.009	spent nuclear fuel storage cost	One time cost	
14.475	TOTAL Lifecycle Cost		

Inflation
2.71%

Years	Ship Acquisition Cost	Ship Acquisition Cost Over 7-Years	Direct Operating Cost	Indirect Operating Cost	Inactivation/ Disposal Cost	Spent Nuclear Fuel Storage Cost	Non-Cumulative Cost/Year	Cumulative Cost/Year
1	**4.06**	**0.58**	0.2335	0.0641	0.59	0.01	4.06	**0.58**
2	4.17	**0.58**	0.2399	0.0658	0.60	0.01	0.00	**1.16**
3	4.28	**0.58**	0.2464	0.0676	0.62	0.01	0.00	**1.74**
4	4.40	**0.58**	0.2530	0.0695	0.63	0.01	0.00	**2.32**
5	4.52	**0.58**	0.2599	0.0713	0.65	0.01	0.00	**2.90**
6	4.64	**0.58**	0.2669	0.0733	0.67	0.01	0.00	**3.48**
7	4.77	**0.58**	0.2742	0.0753	0.69	0.01	0.35	**4.06**
8	4.89		**0.2816 0.**	**0773**	0.71	0.01	0.36	**4.42**
9	5.03		**0.2892 0.**	**0794**	0.73	0.01	0.37	**4.79**
10	5.16		**0.2971 0.**	**0815**	0.74	0.01	0.38	**5.17**
11	5.30		**0.3051 0.**	**0838**	0.76	0.01	0.39	**5.55**
12	5.45		**0.3134 0.**	**0860**	0.79	0.01	0.40	**5.95**
13	5.59		**0.3219 0.**	**0884**	0.81	0.01	0.41	**6.36**
14	5.75		**0.3306 0.**	**0907**	0.83	0.01	0.42	**6.79**
15	5.90		**0.3396 0.**	**0932**	0.85	0.01	0.43	**7.22**
16	6.06		**0.3488 0.**	**0957**	0.87	0.01	0.44	**7.66**
17	6.23		**0.3582 0.**	**0983**	0.90	0.01	0.46	**8.12**
18	6.39		**0.3679 0.**	**1010**	0.92	0.01	0.47	**8.59**
19	6.57		**0.3779 0.**	**1037**	0.95	0.01	0.48	**9.07**
20	6.75		**0.3882 0.**	**1065**	0.97	0.01	0.49	**9.56**
21	6.93		**0.3987 0.**	**1094**	1.00	0.01	0.51	**10.07**
22	7.12		**0.4095 0.**	**1124**	1.03	0.02	0.52	**10.59**
23	7.31		**0.4206 0.**	**1154**	1.05	0.02	0.54	**11.13**
24	7.51		**0.4320 0.**	**1186**	1.08	0.02	0.55	**11.68**
25	7.71		**0.4437 0.**	**1218**	1.11	0.02	0.57	**12.25**
26	7.92	**1.13**	**0.4557**	**0.1251**	1.14	0.02	9.63	**13.96**
27	8.13	**1.13 0.**	**4680**	**0.1285**	1.17	0.02	0.60	**15.69**
28	8.36	**1.13 0.**	**4807**	**0.1319**	1.21	0.02	0.61	**17.43**
29	8.58	**1.13 0.**	**4938**	**0.1355**	1.24	0.02	0.63	**19.19**
30	8.81	**1.13 0.**	**5071**	**0.1392**	1.27	0.02	0.65	**20.97**
31	9.05	**1.13 0.**	**5209**	**0.1430**	1.31	0.02	0.66	**22.76**
32	9.30	**1.13 0.**	**5350**	**0.1468**	1.34	0.02	0.68	**24.58**
33	**9.55**		**0.5495**	**0.1508**	**1.38**	**0.02**	**2.10 26.**	**68**

34	9.81		0.5644 0.	1549	1.41	0.02	0.72	27.39
35	10.08		0.5797 0.	1591	1.45	0.02	0.74	28.13
36	10.35		0.5954 0.	1634	1.49	0.02	0.76	28.89
37	10.63		0.6115 0.	1678	1.53	0.02	0.78	29.67
38	10.92		0.6281 0.	1724	1.57	0.02	0.80	30.47
39	11.21		0.6451 0.	1771	1.62	0.02	0.82	31.29
40	11.52		0.6626 0.	1819	1.66	0.02	0.84	32.14
41	11.83		0.6806 0.	1868	1.71	0.03	0.87	33.01
42	12.15		0.6990 0.	1919	1.75	0.03	0.89	33.90
43	12.48		0.7180 0.	1971	1.80	0.03	0.92	34.81
44	12.82		0.7374 0.	2024	1.85	0.03	0.94	35.75
45	13.16		0.7574 0.	2079	1.90	0.03	0.97	36.72
46	13.52		0.7779 0.	2135	1.95	0.03	0.99	37.71
47	13.89		0.7990 0.	2193	2.00	0.03	1.02	38.73
48	14.26		0.8207 0.	2252	2.06	0.03	1.05	39.77
49	14.65		0.8429 0.	2313	2.11	0.03	1.07	40.85
50	15.05		0.8657 0.	2376	2.17	0.03	1.10	41.95
51	15.45		0.8892 0.	2441	2.23	0.03	1.13	43.08
52	15.87		0.9133 0.	2507	2.29	0.03	1.16	44.25
53	16.30		0.9380 0.	2575	2.35	0.03	1.20	45.44
54	16.75		0.9635 0.	2644	2.42	0.04	1.23	46.67
55	17.20		0.9896 0.	2716	2.48	0.04	1.26	47.93
56	17.67		1.0164 0.	2790	2.55	0.04	1.30	49.23
57	18.14		1.0439 0.	2865	2.62	0.04	1.33	50.56
58	18.64		1.0722 0.	2943	2.69	0.04	1.37	51.92
59	19.14	2.73	1.1013	0.3023	2.76	0.04	23.28	56.06
60	19.66	2.73 1.	1311	0.3105	2.84	0.04	1.44	60.24
61	20.19	2.73 1.	1618	0.3189	2.91	0.04	1.48	64.45
62	20.74	2.73 1.	1933	0.3275	2.99	0.04	1.52	68.71
63	21.30	2.73 1.	2256	0.3364	3.07	0.05	1.56	73.01
64	21.88	2.73 1.	2588	0.3455	3.16	0.05	1.60	77.34
65	22.47	2.73 1.	2929	0.3549	3.24	0.05	1.65	81.73
66	23.08		1.3280	0.3645	3.33	0.05	5.07 86.	80
67	23.71		1.3640 0.	3744	3.42	0.05	1.74	88.53
68	24.35		1.4009 0.	3845	3.51	0.05	1.79	90.32
69	25.01		1.4389 0.	3949	3.61	0.05	1.83	92.15
70	25.69		1.4779 0.	4056	3.70	0.05	1.88	94.04
71	26.38		1.5179 0.	4166	3.81	0.06	1.93	95.97
72	27.10		1.5591 0.	4279	3.91	0.06	1.99	97.96
73	27.83		1.6013 0.	4395	4.01	0.06	2.04	100.00
74	28.59		1.6447 0.	4514	4.12	0.06	2.10	102.10
75	29.36		1.6893 0.	4637	4.23	0.06	2.15	104.25
76	30.16		1.7351 0.	4762	4.35	0.06	2.21	106.46
77	30.97		1.7821 0.	4891	4.47	0.07	2.27	108.73
78	31.81		1.8304 0.	5024	4.59	0.07	2.33	111.06
79	32.67		1.8800 0.	5160	4.71	0.07	2.40	113.46
80	33.56		1.9309 0.	5300	4.84	0.07	2.46	115.92
81	34.47		1.9833 0.	5443	4.97	0.07	2.53	118.45
82	35.40		2.0370 0.	5591	5.11	0.07	2.60	121.04

83	36.36		**2.0922 0.**	**5743**	5.24	0.08	2.67	**123.71**
84	37.35		**2.1489 0.**	**5898**	5.39	0.08	2.74	**126.45**
85	38.36		**2.2071 0.**	**6058**	5.53	0.08	2.81	**129.26**
86	39.40		**2.2670 0.**	**6222**	5.68	0.08	2.89	**132.15**
87	40.47		**2.3284 0.**	**6391**	5.84	0.09	2.97	**135.12**
88	41.56		**2.3915 0.**	**6564**	5.99	0.09	3.05	**138.17**
89	42.69		**2.4563 0.**	**6742**	6.16	0.09	3.13	**141.30**
90	43.85		**2.5229 0.**	**6925**	6.32	0.09	3.22	**144.51**
91	45.04		**2.5912 0.**	**7112**	6.50	0.10	3.30	**147.82**
92	**46.26**	**6.61**	**2.6615**	**0.7305**	6.67	0.10	56.26	**157.82**
93	47.51	**6.61 2.**	**7336**	**0.7503**	6.85	0.10	3.48	**167.91**
94	48.80	**6.61 2.**	**8077**	**0.7706**	7.04	0.10	3.58	**178.09**
95	50.12	**6.61 2.**	**8838**	**0.7915**	7.23	0.11	3.68	**188.38**
96	51.48	**6.61 2.**	**9619**	**0.8130**	7.42	0.11	3.77	**198.76**
97	52.87	**6.61 3.**	**0422**	**0.8350**	7.63	0.11	3.88	**209.25**
98	54.31	**6.61 3.**	**1246**	**0.8576**	7.83	0.11	3.98	**219.84**
99	**55.78**		**3.2093**	**0.8809**	**8.04**	**0.12**	**12.25 232.**	**09**
100	57.29		**3.2963 0.**	**9047**	8.26	0.12	4.20	**236.29**

Table 4. 33-Year Lifecycle Cost Model.

Color Legend

Bold Numbers – Base Numbers used for calculations

Green Highlight- New Ship Construction

Red Highlight – Ship Disposal

Table 4 shows a model of the 33-year lifecycle cost of an aircraft carrier adjusted for inflation at an average annual rate of 2.71% [39] over 100 years. The bold numbers reflect the initial costs used to configure the model. They are also the numbers used to determine the cumulative and non-cumulative annual costs. For example, the cost to build a carrier in 26 years is the summation of the cumulative annual cost of a carrier at 25 years, the ship acquisition cost over seven years, the direct cost at 26 years and the indirect operations costs at 26 years (12.25 + 1.13 + 0.4557 + 0.1251 = $13.96 billion). The green highlighted rows represent the beginnings of carrier, construction (for simplicity, it was modeled as a 7year evenly divided process including commissioning) and the red rows represent the end of carrier lifecycles (includes inactivation, disposal, and spent nuclear fuel costs).

Table 5 is a cumulative cost comparison of the two-lifecycle approaches. It shows that although their costs are similar at 100 years (Figure 30), the 33-Year Lifecycle Philosophy (33LCP) is overall more cost effective than the 50-Year Lifecycle Philosophy (50LCP) because the Navy receives more performance for equal to or less cost. For example, in respect to performance, according to the 33LCP the Navy would receive three modernized Nimitz-class aircraft carriers over 100 years as opposed to two. Each carrier would be able to achieve greater performance (work accomplished) due to the elimination of the three to four year lay-up period (RCOH). This means that some of the strain to the fleet (i.e., equipment, personnel, and ship maintenance) from extended deployments would no longer be the result of RCOH delivery delays. In addition, the combatant commanders would benefit from the carriers increased operational availability as deployable assets, which would enhance their (CCDRs) ability to utilize those assets. From a cost perspective, the second ship constructed in the 33LCP ($7.92 billion) is $4.56 billion less expensive than the second ship of the 50LCP ($12.48 billion). The total cost of ownership (TCOO) of the 33LCP over 100 years is $53.32 billion less expensive than the 50LCP over 100 years. Additionally, the average cost per year for the 33LCP over 100 years is approximately $530 million less expensive than the 50LCP over 100 years.

Years	Ship Acquisition Cost	33-Year Cumulative Cost/Year	50-Year Cumulative Cost/Year	33-Year Average Annual Cost Over 100-Years	50-Year Average Annual Cost Over 100-Years
1	4.06	0.58	0.58	65.18	65.72
2	4.17	1.16	1.16		
3	4.28	1.74	1.74		
4	4.40	2.32	2.32		
5	4.52	2.90	2.90		
6	4.64	3.48	3.48		
7	4.77	4.06	4.06		
8	4.90	4.42	4.42		
9	5.03	4.79	4.79		
10	5.16	5.17	5.17		
11	5.30	5.55	5.56		
12	5.45	5.95	5.95		
13	5.60	6.36	6.36		
14	5.75	6.79	6.79		

15	5.90	7.22	7.22		
16	6.06	7.66	7.66		
17	6.23	8.12	8.12		
18	6.40	8.59	8.59		
19	6.57	9.07	9.07		
20	6.75	9.56	9.57		
21	6.93	10.07	10.07		
22	7.12	10.59	10.60		
23	7.31	11.13	11.13		
24	7.51	11.68	11.68		
25	7.71	12.25	13.76		
26	7.92	13.96	15.84		
27	8.14	15.69	17.95		
28	8.36	17.43	18.56		
29	8.58	19.19	19.19		
30	8.82	20.97	19.84		
31	9.06	22.76	20.50		
32	9.30	24.58	21.18		
33	9.55	26.68	21.88		
34	9.81	27.39	22.60		
35	10.08	28.13	23.34		
36	10.35	28.89	24.10		
37	10.63	29.67	24.88		
38	10.92	30.47	25.68		
39	11.22	31.29	26.50		
40	11.52	32.14	27.35		
41	11.83	33.01	28.21		
42	12.15	33.90	29.11		
43	12.48	34.81	31.80		
44	12.82	35.75	34.53		
45	13.17	36.72	37.27		
46	13.52	37.71	40.05		
47	13.89	38.73	42.85		
48	14.27	39.77	45.68		
49	14.65	40.85	48.54		
50	15.05	41.95	52.98		
51	15.46	43.08	54.11		
52	15.88	44.25	55.27		
53	16.31	45.44	56.47		
54	16.75	46.67	57.70		
55	17.20	47.93	58.96		
56	17.67	49.23	60.25		
57	18.15	50.56	61.58		
58	18.64	51.92	62.95		
59	19.15	56.06	64.35		
60	19.66	60.24	65.80		
61	20.20	64.45	67.28		

62	20.74	68.71	68.80		
63	21.31	73.01	70.36		
64	21.88	77.34	71.96		
65	22.48	81.73	73.61		
66	23.09	86.80	75.30		
67	23.71	88.53	77.04		
68	24.35	90.32	78.83		
69	25.01	92.15	80.66		
70	25.69	94.04	82.55		
71	26.39	95.97	84.48		
72	27.10	97.96	86.47		
73	27.84	100.00	88.51		
74	28.59	102.10	90.60		
75	29.37	104.25	98.50		
76	30.16	106.46	106.45		
77	30.98	108.73	114.47		
78	31.82	111.06	116.80		
79	32.68	113.46	119.20		
80	33.57	115.92	121.66		
81	34.48	118.45	124.19		
82	35.41	121.04	126.78		
83	36.37	123.71	129.45		
84	37.36	126.45	132.19		
85	38.37	129.26	135.00		
86	39.41	132.15	137.89		
87	40.48	135.12	140.86		
88	41.58	138.17	143.91		
89	42.70	141.30	147.04		
90	43.86	144.51	150.25		
91	45.05	147.82	153.55		
92	46.27	157.82	156.95		
93	47.52	167.91	167.22		
94	48.81	178.09	177.59		
95	50.13	188.38	188.05		
96	51.49	198.76	198.61		
97	52.89	209.25	209.28		
98	54.32	219.84	220.05		
99	55.79	232.09	230.93		
100	57.30	236.29	247.83		
Total Cost Of Ownership		6518.44	6571.75		

Table 5. 50LCP vs. 33LCP Cost Comparison.

Color Legend

Green Highlight- New Ship Construction

Blue Highlight- RCOH

Red Highlight – Ship Disposal

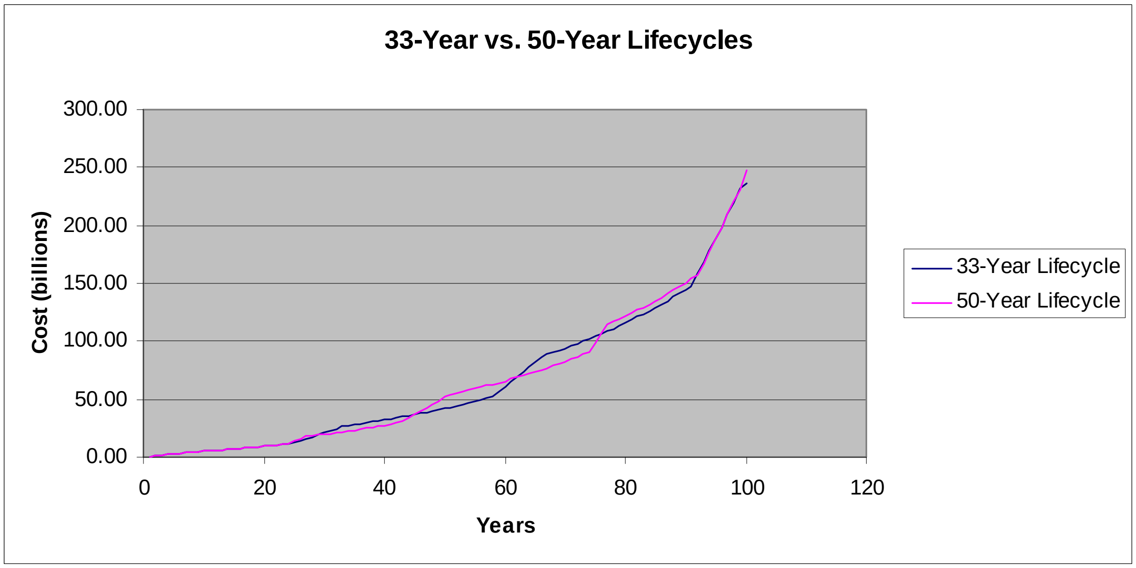

Figure 30. 50 vs. 33 Year Lifecycle

The 33LCP is the best of solutions proposed by this research to answer the thesis question because it meets the criteria for cost and time effectiveness defined by this study. According to Chapter I, C_{eff} was any change in planning, scheduling, and/or conducting an RCOH that resulted in less cost for the more performance (work accomplished) or less cost for the same amount of performance. 33LCP meets these criterions. As stated previously, under the 33LCP, the Navy would procure three brand new carriers as opposed to one under the 50LCP. This increases the ship's level modernization and reduces the maintenance costs due to aging equipment. With the elimination of an RCOH,

T_{eff} is one. T_{eff} of one increases the operational availability of aircraft carriers since there is no longer a 4-year mean down time with the potential for further delays. Also, since NGC has built all of the Nimitz-class carriers for the Navy (Chapter

V, Section B), the learning curve and cost associated with constructing those type of vessels has been realized whereas the learning curve and cost associated with RCOHs remains fairly uncertain. Further studies on the relationship between cost, maintenance, operational availability, and risks associated with eliminating an RCOH from a carrier's lifecycle are warranted and beyond the scope of this research. However, with that said, it is the author's opinion that the 33-year lifecycle philosophy is the best of the solutions offered within the scope of this thesis to stem the Navy's challenge of confronting the increasing costs and schedule durations associated with refueling and complex overhauls.

E. FUTURE WORK

This section contains brief questions on areas for future research noted in the course of writing this thesis.

- What types of non-nuclear maintenance can be conducted pier side or through underwater husbandry? Additionally, what types of work can be done outside of dry-dock and what are the implications of doing work inside and outside of dry-dock?
- What is the impact to a carrier's operational availability (i.e., crew training and operational readiness) associated with decreasing a RCOH's duration?
- What are the relationships between time in dry-dock and maintenance concepts?
- When is the most opportune time to improve upon a carrier's capabilities? When does cost the least to do and where should it should it be done?
- What is the impact to an aircraft carrier's operational readiness associated with removing combat system upgrades from a RCOHs work package?
- By deferring modernization efforts to planned incremental availabilities, what is the impact to the overall aircraft carriers maintenance cycle?
- By reducing the number of aircraft carries in the Navy, what are the impacts to national security, manning, and cost?

F. CHAPTE R SUMMARY

This chapter presented the conclusions and future work generated from completing this thesis.

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